

UNCLASSIFIED

AD NUMBER

AD121430

CLASSIFICATION CHANGES

TO: unclassified

FROM: confidential

LIMITATION CHANGES

TO:

Approved for public release, distribution unlimited

FROM:

Distribution authorized to U.S. Gov't. agencies and their contractors; Specific Authority; 20 Oct 56. Other requests shall be referred to Office of Naval Research, Code 461, Washington, DC.

AUTHORITY

OCA; October 20, 1968 IAW document markings.; DTNSRDC ltr., dtd December 15, 1981.

THIS PAGE IS UNCLASSIFIED

UNCLASSIFIED

AD _____

DEFENSE DOCUMENTATION CENTER

FOR

SCIENTIFIC AND TECHNICAL INFORMATION

CAMERON STATION ALEXANDRIA, VIRGINIA

DOWNGRADED AT 3 YEAR INTERVALS:

DECLASSIFIED AFTER 12 YEARS

DOD DIR 5200.10



UNCLASSIFIED

CONFIDENTIAL

AD 121430

Armed Services Technical Information Agency

Reproduced by
DOCUMENT SERVICE CENTER
KNOTT BUILDING, DAYTON, 2, OHIO

This document is the property of the United States Government. It is furnished for the duration of the contract and shall be returned when no longer required, or upon recall by ASTIA to the following address: Armed Services Technical Information Agency, Document Service Center, Knott Building, Dayton 2, Ohio.

NOTICE: WHEN GOVERNMENT OR OTHER DRAWINGS, SPECIFICATIONS OR OTHER DATA ARE USED FOR ANY PURPOSE OTHER THAN IN CONNECTION WITH A DEFINITELY RELATED GOVERNMENT PROCUREMENT OPERATION, THE U. S. GOVERNMENT THEREBY INCURS NO RESPONSIBILITY, NOR ANY OBLIGATION WHATSOEVER; AND THE FACT THAT THE GOVERNMENT MAY HAVE FORMULATED, FURNISHED, OR IN ANY WAY SUPPLIED THE SAID DRAWINGS, SPECIFICATIONS, OR OTHER DATA IS NOT TO BE REGARDED BY IMPLICATION OR OTHERWISE AS IN ANY MANNER LICENSING THE HOLDER OR ANY OTHER PERSON OR CORPORATION, OR CONVEYING ANY RIGHTS OR PERMISSION TO MANUFACTURE OR USE OR SELL ANY PATENTED INVENTION THAT MAY IN ANY WAY BE RELATED THERETO.

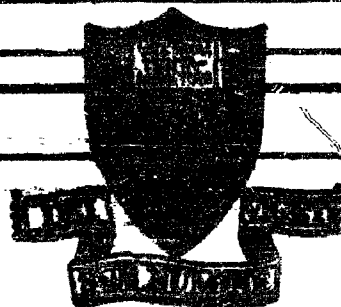
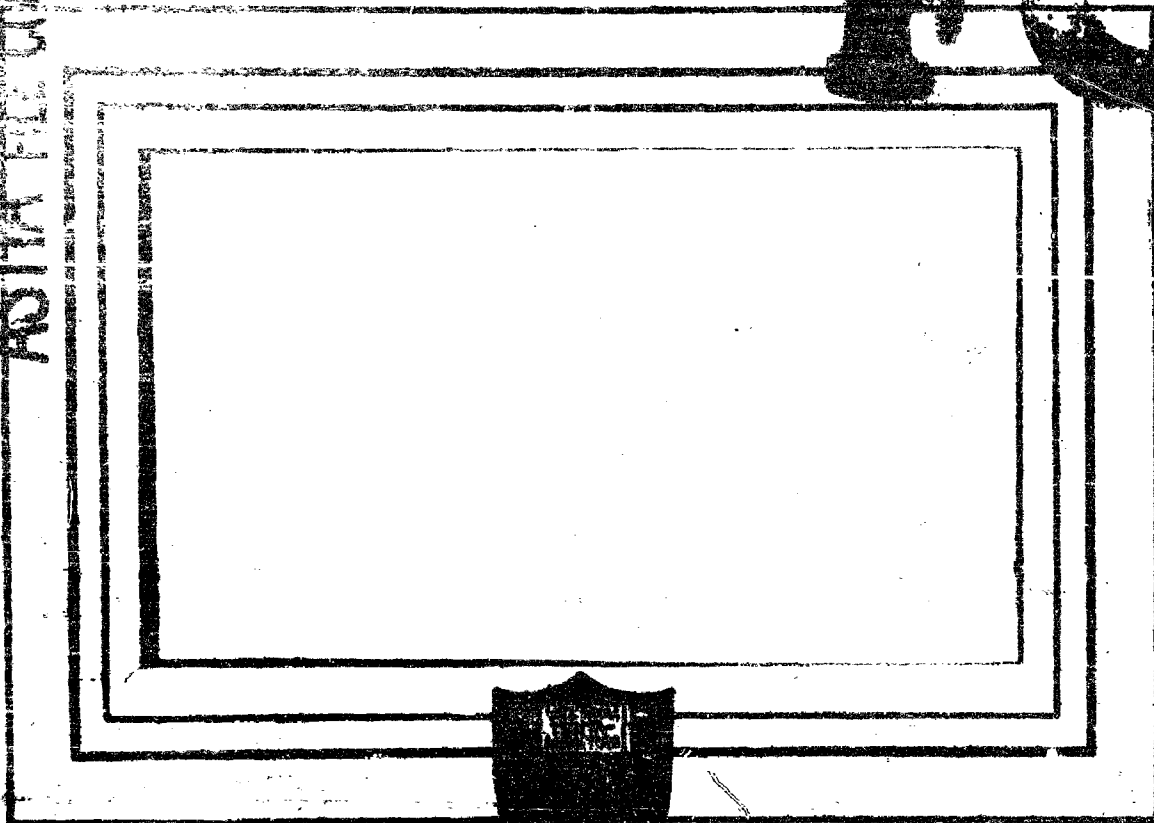
CONFIDENTIAL

AD No. 11430

ASFA FILE COPY

CONFIDENTIAL

FC



PRINCETON UNIVERSITY

DEPARTMENT OF AERONAUTICAL ENGINEERING

FEB 11 1957

11430

CONFIDENTIAL

TWO DIMENSIONAL TESTS OF A 23015 AIRFOIL WITH
A JET SPOILER AND VARIOUS FLAPS

by

W. S. Childress
A. V. Gould

Contract #Nonr 1858(01)

Report No. 365

October 20, 1956

This document has been reviewed in accordance with
OPNAV FORM 5510, 17, paragraph 8. The security
classification assigned here is correct.

Date: 4/1/59 for E. S. HENRY
By direction of
Chief of Naval Research (Code 464)

CONFIDENTIAL

58A

11709

**NOTICE: THIS DOCUMENT CONTAINS INFORMATION AFFECTING THE
NATIONAL DEFENSE OF THE UNITED STATES WITHIN THE MEANING
OF THE ESPIONAGE LAWS, TITLE 18, U.S.C., SECTIONS 793 and 794.
THE TRANSMISSION OR THE REVELATION OF ITS CONTENTS IN
ANY MANNER TO AN UNAUTHORIZED PERSON IS PROHIBITED BY LAW.**

TABLE OF CONTENTS

	Page
Acknowledgment	i
List of Symbols	ii
Summary	iv
Introduction	1
Previous Jet Spoiler Investigations	5
Apparatus and Tests	6
Models	8
Test Procedures and Data Reduction	9
Results	12
Discussion	13
Extension of Data to Three-Dimensional Flow	19
Conclusions and Recommendations	20
Appendix	21
References	24

ACKNOWLEDGMENT

The authors wish to express their sincere appreciation to the staff of the Subsonics Aerodynamics Laboratory of Princeton University.

Particular thanks go to T. P. Sweeney whose preliminary studies laid the groundwork for this study and to Margaret Miller, who provided constant assistance in its preparation.

List of Symbols (See Fig. 6)

- C_L Two dimensional lift coefficient, spoiler off.
- C_m Two dimensional coefficient of moment about the aerodynamic center, spoiler off.
- ΔC_L Lift coefficient increment due to aerodynamic effects of the spoiler.
- ΔC_m Moment coefficient increment due to the aerodynamic effects of the spoiler.
- ΔC_{L_m} Lift coefficient increment due to the momentum contribution of the spoiler.
- ΔC_{m_m} Moment coefficient increment due to the momentum contribution of the spoiler.
- \bar{x} Distance along the profile chord line from the leading edge to the center of the spoiler slot expressed as a fraction of the total chord.
- V_j Flow velocity in the spoiler slot, ft./sec.
- θ Angle of the spoiler slot with respect to the profile chord line, in degrees.
- Flap angle in degrees.
- δ_f Angle of attack in degrees.
- S Section area in square feet.
- C_p Static pressure/ q_t .
- C Profile chord in feet.
- C_f Flap chord, measured along its chord line, in feet.
- V_∞, V_∞ Free stream velocity in ft./sec.
- q_t Test section dynamic pressure in lbs./ft.²
- q_j Slot dynamic pressure in lbs./ft.²
- ρ Flow density in slugs/ft.³
- μ Viscosity coefficient in lb.-sec./ft.²
- T_t Test section temperature in °F.
- T_{ch} Model chamber temperature in °F.
- T_c Cold-chamber plate temperature in °F.

R_n Reynolds' number. ($R_n = \frac{\rho V_o c}{\mu}$)

w Weight flow through the slot, in lbs./sec.

g Acceleration of gravity in ft./sec².

q_o Two dimensional slope of lift curve, per degree.

C_q Quantity flow coefficient through slot. ($C_q = \frac{w}{\rho g V_o S}$)

C_μ Momentum flow coefficient through slot. ($C_\mu = \frac{w V_i}{\rho q_o S}$)

E Spoiler efficiency ($E = \frac{-\Delta C_L}{C_\mu}$)

Subscripts

j Jet conditions

m Model conditions

t Test section conditions

SUMMARY

Two dimensional model tests of an NACA 23015 airfoil equipped with a jet spoiler and various flaps were conducted in the 2" x 36" smoke tunnel (smoke line studies), and in the 1' x 1' throat of the instructional tunnel (pressure distribution studies). These tests precede three dimensional force tests, flight tests of an L-21 airplane, and design studies. In anticipation of this work, the data herein was compiled to establish the most effective jet spoiler configuration for the light liaison plane, but it is felt that this control has possible application to heavy, high speed aircraft.

Specifically, the influence of various parameters on the lift reduction only were studied. The major variables in the problem were isolated in turn, and it was found that the major ones are C_μ , θ , \bar{x} , and α . For the NACA 23015 equipped with a .25c single slotted flap, a configuration which approximates that found on most liaison airplanes, optimum effectiveness for an angle of attack range of 0 to 15° was achieved for $\theta = 60^\circ$, $\bar{x} = .65$. The spoiler was tested over a variety of flaps, and it was found that performance over single slotted, double slotted, and plain types is promising, lift coefficient reductions of .8 being reached at a C_μ of .1.

Effectiveness of the control over a plain wing was found to be slightly greater than this, a ΔC_l of -.9 reached at the same blowing quantity. Using this data, preliminary calculations for the L-21 airplane show that a $P_{b/2v}$ of .07 can be developed using a blowing system capable of reaching a C_μ of .05. Since this figure is small compared to the blowing quantities for most high lift blowing systems, it is possible that the jet spoiler can be incorporated practically into circulation or boundary layer control airplane.

A brief check proved the pitching moment to change little with blowing. It was found that jet reaction accounted for roughly 10% of the lift reduction. Sufficient data is presented to predict accurately lift reductions due to the jet spoiler over a wide range of practical installations with particular emphasis on a .25c slotted flap.

I. INTRODUCTION

Current interest in STO and VTOL machines stems from the versatility of liaison, transport, and reconnaissance aircraft capable of operating from small, rough fields, yet able to reach high cruising speeds. Unfortunately, the simple aileron as a solution to the lateral control problem finds practical application in only a small part of this enlarged speed range. At lower speeds, ailerons occupy valuable space at the trailing edge of the wing, yet have very little control power. At high flight velocities, aerodynamic flutter and control reversal due to wing twist become severe problems, while the high control forces demand heavy power systems. The desirability of powerful, responsive lateral control near the minimum speed of aircraft having full span high-lift devices, together with the high speed considerations, necessitates investigation of entirely new forms of control.

PROPOSED METHODS OF ACHIEVING LATERAL CONTROL
ON HIGH LIFT AIRPLANES

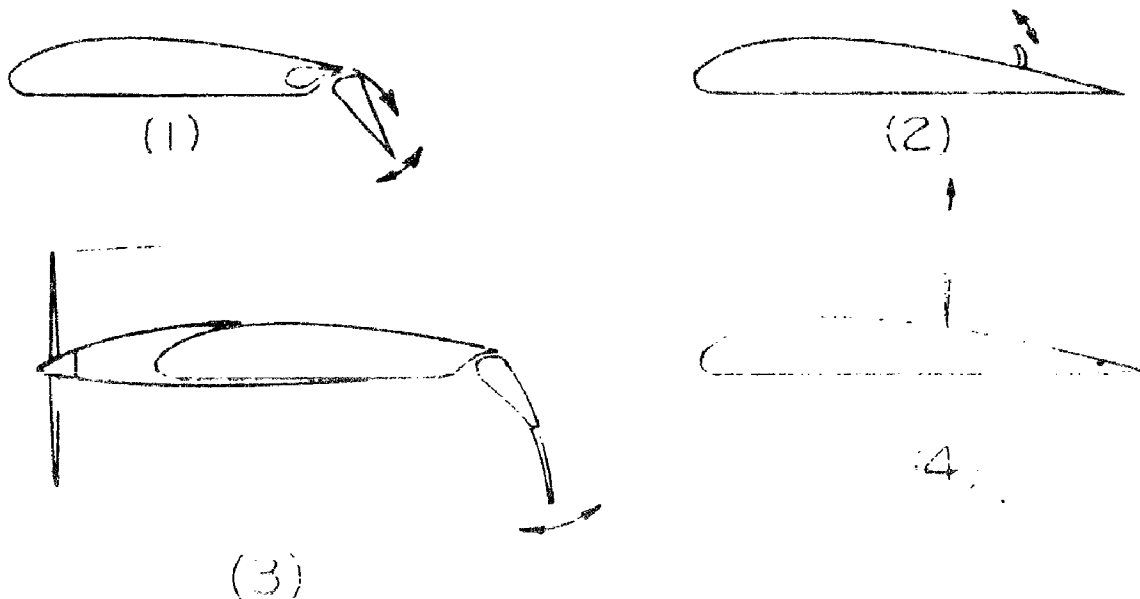


FIG. A

Figure A displays several lateral control systems now under consideration for high lift airplanes. Although the increasing interest in the ducted fan suggests methods utilizing vanes in the slipstream and variable propeller rpm, the designs pictured represent the most obvious solutions for conventional one or two engine light liaison aircraft.

Conventional ailerons can be retained, yet full span flaps realized, in a system employing some BAC to reattach the flow to the wing. This arrangement (1) uses ailerons acting differentially from a drooped position at low speeds, with blowing over the full length of the flaps and ailerons. Since the control derives most of its power from the flow over the flap, loss of the high blowing quantity required produces almost total loss of control, and constitutes a definite hazard at low altitudes.

The mechanical spoiler has found considerable application to high speed aircraft due to favorable aero-elastic effects on the wing, low hinge moments, favorable yawing action, and adequate control power. However, response is often sluggish, control effectiveness generally falls off near the stall, and satisfactory overall performance is usually achieved at the expense of mechanical complexity and weight sacrifices. Finally, for a low flying plane, lateral control at the expense of a net loss in lift constitutes a possible flying hazard.

If high lift at low speeds is achieved by means of deflection of the propeller slipstream, differential movement of flaps immersed in the flow is an attractive means of lateral control (3). The response of such a system remains to be tested, however, and there would most certainly be large adverse yawing moments. The latter problem can be overcome by differentially varying the thrust of the propellers in a two engine machine, but once again response is doubtful, and weight penalties must be expected.

A final system (h) resorts entirely to jet reaction for control moment, a system which might have some merit for aircraft having a low polar moment of inertia about the longitudinal axis, especially if hovering flight is achieved. Obviously the flow quantities required would be large, and for a small craft designed to STOL requirements, it appears that such a system would not only be too heavy but also overlooks the control power made available by fluid flow over the wing.

In addition to these devices, numerous combinations have been advanced, most of them attempting to solve each of the several important problems involved in slow flight control with a modification of one of these basic types. These fundamental considerations can be summarized as follows:

- (1) Control should be retained up to the minimum speed achieved with any high lift devices employed.
- (2) Control should be available in the event of power failure of any blowing systems used.
- (3) Control should be adequate over full span flaps, as well as over a plain wing in cruising flight.
- (4) The weight and mechanical complexity of the system must be held to a minimum.
- (5) For low level aircraft, a net loss in lift for purposes of control is highly undesirable.
- (6) The system must be capable of high rolling moments at low flight velocity.

$P_{b/2V}$ is not the true measure of lateral control response at low V *.

The jet spoiler has been suggested as a means overcoming a great many control problems at the extremes of the flight spectrum of current operational aircraft. At high supersonic speeds, advocates feel that high wave drag due to it is probable that $\ddot{\phi}$ the acceleration of roll, is the true test of control response as $V \rightarrow 0$.

to control can be minimized, and the wing need not be weakened by the existence of ailerons on the trailing edge. At very low speeds, moreover, the induced separation magnifies the momentum effect of the jet. Because of the low power required for the system, emergency operation on ram air alone can be foreseen. (Ref. (18) describes such an emergency system). Use of the spoiler with BLC blowing on the wing or jet circulation control could, if designed carefully, result in a highly powerful system capable of controlling without a net loss of lift. This combined system would most certainly be lighter and less complicated than the BLC unit plus a control device operating on a fundamentally different principal. It is with these possibilities in mind that this study of the two-dimensional characteristics of the jet spoiler was undertaken.

II. PREVIOUS JET SPOILER INVESTIGATIONS

On the basis of References 21 and 22, it can be stated that the jet spoiler is not a completely new device, however, it is only with the advent of circulation control systems using high velocity blowing that serious consideration has been given to the device for a completely integrated control system. Several investigators have recognized the advantages of an air jet as a means of both decreasing lift and increasing drag, but on the basis of the information available to the authors, the experimentation on the subject to date has been of an exploratory nature only.

Recent studies conducted at the David Taylor Model Basin (Ref. 19) were quite promising, a high velocity jet being applied to an NACA 64A010 section. Three dimensional tests by Lowry and Turner (Ref. 18) confirm the possibility of utilizing ram air for emergency operation of the spoiler.

Work in the field first began at Forrestal Research Center in 1954, when studies of a jet spoiler on an USAF 358 airfoil were initiated. After the major parameters were investigated, work was begun to equip an L-21 airplane with a blowing slot in the vicinity of the aileron on the right wing panel. Preliminary rolling tests (Ref. 16) and pressure distribution studies (Ref. 17) established the unique and promising aspects of the device, though the power of the system was not sufficient to equal the performance of fully deflected ailerons.

On the basis of these investigations, a more general study was felt necessary before the full capabilities of the jet spoiler could be realized on aircraft, beginning with a complete study of the two dimensional characteristics.

III. APPARATUS AND TESTS

Initial tests were performed in the 2" x 36" smoke tunnel at Forrestal Research Center (Figs. 1 and 8). A variety of flap configurations on the NACA 23015 airfoil were tested, an effort was made to determine the optimum slot position and blowing angle, and the influence of angle of attack, flap angle, and flap chord on the lift fall off, $-\Delta C_L$. Lift coefficients were measured by the slipstream deflection method (Ref. 13) and comparison of this data with that of succeeding tests indicates that the method gives reasonably accurate results. The momentum coefficients were determined from an orifice plate flow meter assuming incompressible flow. It is estimated that a maximum error of 4% is introduced into the C_μ calculations by this assumption. These tests were run at a Reynolds' number of approximately 2.5×10^5 .

In the second phase of testing, pressure distributions over an NACA 23015 airfoil with a .25c slotted flap were measured for several slot angles and positions, the test facility being the two dimensional throat of the instructional tunnel at Forrestal Research Center (Fig. 9). The pressure distribution was indicated by a multiple manometer and photographed. C_μ was measured by an orifice plate flow meter together with total head and static pressure taps at the slot. Since these pressures were also recorded on film, all readings were taken at the same instant. The pressures were plotted and integrated graphically, the flap pressures being plotted on the horizontal reference line. This necessitated that a correction factor for flap deflection be applied to the flap contribution to lift. For the pressure distribution tests, the normal force was used in determining the lift coefficient. Temperatures recorded for density calculation were measured by thermocouples and a Wheatstone bridge. The complete test rig is pictured

in Fig. 1. These tests were performed at a Reynolds Number of 1.08×10^5 . A final phase of tests were run at a RN of $.54 \times 10^6$ in order to increase the values of C_M 's measured. This phase was performed with the same rig as was used for the preceding wind tunnel tests. For all tests blowing air was supplied by compressors; in phase III, two blowers were staged in order to boost the C_M 's.

IV. MODELS

Models for the two dimensional smoke tunnel were constructed of wood and plastic, the rear center portion being hollowed to act as a settling chamber for the jet. Base sections were made for each of the jet angles tested (30, 45, 60, and 90°), and in each one slots were milled at locations from .20 to .70c. The slots not in use were taped with electrical tape. The various flaps were attached to these base sections, each flap adjustable from 0 to 50 degrees. Air was introduced through the 1¹/₂" brass tube which also acted as a support and axis of rotation (Fig. 1).

The pressure distribution model was fitted with 48 pressure taps on the upper and lower surfaces, and space was provided for spoiler locations at .50c and .65c (Fig. 7). The slot angle was varied by screwing removable brass plates into the model into which the proper angle slot was milled. The blowing air was introduced through a flexible hose to the center of the model as is shown in (Fig. 1)

V. TEST PROCEDURES AND DATA REDUCTION

The parameters considered C_{μ} , $-\Delta C_L$, α , δ_f , θ , C_f , flap type, and \bar{x} were investigated in turn until the effect of each on overall spoiler effectiveness could be ascertained.

A base plot of $-\Delta C_L$ vs. C_{μ} was chosen, primarily because both the wing tip helix angle and rolling moment coefficient of an airplane are linear with ΔC_L , and C_{μ} is believed to be a reasonable indication of blowing quantity for any device which contributes momentum effects. It follows that spoiler efficiency (or effectiveness) can be defined by

$$E = \frac{-\Delta C_L}{C_{\mu}}$$

In general, angle of attack was varied in increments of 4° , other parameters held constant. At each α , lift reductions were measured for various amounts of blowing. In the wind tunnel testing, pictures of the manometer board were taken for no blowing and approximately five settings of blowing quantity, and the C_{μ} was determined during data reduction. In the smoke tunnel, increments in lift were determined using the slipstream deflection method described in (Ref. 13). The C_L vs. α curve was established by setting the angle of zero lift as the point where the stagnation streamline remained horizontal up to the stagnation point, a transit used to establish the horizontal reference.

The errors involved in measuring C_L are of course completely different for smoke tunnel and wind tunnel methods. Remembering the small angle approximations, as well as the accuracy of these techniques in previous testing, it is suggested that the following tolerances were set in the measurement of

Smoke tunnel	$\pm 5\%$ maximum
Wind tunnel	$\pm 3\%$ maximum

Because of the scale of testing, C_{μ} is the most difficult parameter to measure for any blowing device. Boundary layer effects in the slot make the jet velocity and slot area difficult to measure, thereby making mass flow difficult to evaluate at the model. The procedure used most often in this laboratory and was followed in these tests is based upon an orifice plate flow meter which can be calibrated to yield mass flow vs. pressure drop ($\frac{W}{g}$ vs. ΔP_0). Several sets of C_{μ} 's were calculated directly, and a calibration curve of q_j vs. C_{μ} established. The following equations are relevant to this procedure.

$$C_{\mu} = \frac{W V_j}{g q_{\tau} S} = \frac{2 A_j q_j}{g S q_{\tau}}$$

Now if A_j is assumed constant, and since S and q_{τ} can be evaluated independently from blowing conditions,

$$C_{\mu} = K \frac{q_j}{q_{\tau}}$$

Comparisons of this line with the more exact computations indicated a maximum error of 2%. Even greater accuracy was obtained by correcting for change in the effective slot area with q_j . The largest experimental error expected occurs in the measurement of q_j . In the wind tunnel model a static pressure tap in the slot and a stagnation pressure tube in the model chamber were assumed sufficient, although a static pressure survey along the slot is advised for more precision. Finally, a maximum error of 4% is introduced by the assumption of incompressible flow. The error expected in the measurement of C_{μ} , with these sources of error in mind, is $\pm 6\%$.

The remaining parameters were measured with sufficient accuracy to be neglected here. Some question as to the meaning of spoiler angle has been raised by other writers (See Ref. 14), since momentum effects in the absence of free stream velocity often yield slightly different effective jet angles.

Since these effects are small, (on the order of ± 3 degrees) and because the slot angle is not critical for small changes, the orientation is defined on the basis of angle of the slot walls with respect to the chord line of the airfoil.

VI. RESULTS

The data displayed in Figures 10 to 37 covers the three phases of testing, which can be broken down as follows:

<u>Phase</u>	<u>Parameters Varied</u>	<u>Tunnel</u>	<u>RN</u>	<u>Flap</u>
I	$\alpha, \bar{x}, \delta_f, \theta, C_f$ flap true	smoke	2.5×10^5	.25c slotted " D.C. .20c split .25c plain .49c slotted .44c plain
II	$\alpha, \delta_f, \theta, \bar{x}$	wind, pressure distribution	1.07×10^6	.25c slotted
III	α, δ_f	wind	51×10^6	.25c slotted

The smoke tunnel pictures (Figs. 3 to 5) are offered as representative of the flow picture with spoiler in operation. In particular the path of the jet and the well defined separation point are shown. No drag information is presented, though (Ref. 20) indicates that the jet spoiler effects considerable drag increases (ΔC_d on the order of .1). From a jet control viewpoint, this behavior produces favorable yawing moments and is highly desirable. It is possible that symmetrical spoiling will prove a practical means of controlling drag. Application of such a system to dive braking and landing roll braking should be considered.

Limited pitching moment data is contained, though it appears that for blowing in the vicinity of the mid chord point pitching moment effects are quite low. Intuitively, pitching moment due to the action of the jet becomes rapidly nose down as the spoiler is moved farther to the rear of this point. Fig. 29 indicates slight nose down pitching moment increments with the spoiler at .65c.

Typical pressure distributions in phase II are given in Figs. 35 and 36. In particular, the pressure drop aft of the spoiler should be noted, as well as the overall decrease in circulation as the blowing is applied.

VII. DISCUSSION

1. General

A spoiler is generally thought of as some device which, when projected from the upper or lower surface of a wing, changes the aerodynamic forces applied to it. The resulting breakdown of continuous flow is referred to as separation, and can be associated with changes in circulation and pressure distribution about the surface. The existence of the separated region precludes the use of the normal tools of theoretical analysis (see appendix), and it is hoped that the data herein presented will be of value in the development of semi-empirical approaches to the problem. During the compilation of this data several characteristics of spoiler flow, i.e. forced separation, were found to act simultaneously toward reduction in wing lift, these are:

1) Modification of the pressure distribution within the separated region.

In Phase II of testing, pressure drops were observed aft of the spoiler slot. This phenomena tends to reduce the "response" of the spoiler control.

2) Direct effect on the circulation of the wing. Since the jet supports a well defined boundary (in effect a stagnation streamline), the effective thickness and camber of the profile are severely modified. (Admittedly, use of the term "circulation" should be limited to steady, attached flow; but the effect of forced separation, is similar to that of other circulation control devices)

3) Effect on induced flow through flap slots within the separated region.

This becomes critical only for low values of $C_{p\alpha}$.

4) Direct reaction of the jet at the profile. By definition, the momentum reaction expressed non-dimensionally is equal to $C_{p\alpha}$.

These effects are functions in one form or another of the various parameters studied, and cannot be considered as completely isolated phenomena.

2. Effect of Angle of Attack

As can be seen in Fig. 16 blowing efficiency, defined as $-\Delta C_L / C_M$ is greatest for high C_M 's at low α , and low C_M 's at high α . This is a good indication of the ease with which the circulation about the profile can be altered at various angles of attack. The Figure referred to is for a spoiler location x of .65. It is important to realize that these curves can reverse themselves for another spoiler location. As will be discussed in the next section, the optimum position for the spoiler is intimately affected by the angle of attack.

Figs. 10 and 11 give the effect of RN and C_M on the basic lift curve. It is significant, we feel, that the effective slope of the lift curve is affected by blowing, for in certain cases where symmetrical spoilers might be used to increase the airplane drag, such behavior would have an important effect upon the stability. Once again, spoiler location will influence the relative importance of this parameter.

Figs. 12 to 15 give a good indication of the influence of angle of attack on the spoiler effectiveness. At high angles of attack, most data displayed a fall off in the efficiency of high blowing due to the stalling of the profile. For constant C_M , a fall off in C_L of from 0 to .3 was observed while varying α from 0 to 12° .

It is obvious that if a jet spoiler type control is to be designed, the range of angle of attack through which operation is desired will influence the choice of configuration. The problem is not so much what a given spoiler can achieve at one angle of attack, but how its efficiency varies throughout this range.

In phase III of testing, small increases in lift were noticed at low $C_{\mu}'s$, and 0 angle of attack. This effect has been mentioned by other investigators, and can be traced to a greater lift increase due to the pressure drop aft of the spoiler than lift reduction due to decay of circulation. It was found that this disturbing condition could be alleviated by sealing off the gap of the slotted flap. (See Fig. 23). It is believed, therefore, that a good portion of the pressure drop is due to the induced flow through the flap slot caused by the spoiler jet. It should be mentioned here that the pressure aft of the slot at all times had a low gradient, obviously due to turbulent mixing.

A second critical region of operation occurs at low angles of attack, with the spoiler blowing at $\alpha = 30^\circ$, \bar{x} less than .5. Early smoke tunnel studies revealed that for low $C_{\mu}'s$, the flow would separate at the spoiler slot, but reattach before it reached the trailing edge. The stream of high energy air then reenergized the boundary layer and effected slight lift increases. This effect was never noticed for the spoiler configuration finally selected for extensive study.

3. Effect of \bar{x}

As has been mentioned, the spoiler chordwise position is of great importance in determining the overall operation of the jet spoiler. Figs. 17, 18, and 19 indicate its effect. Although the optimum position moves forward with angle of attack, a location in the region of .60 to .70 offers the highest efficiency throughout the angle of attack range studied. The optimum position for any α is a function of the stability of the boundary layer along the chord, an observation that points up an important limitation of these studies. If a lift augmentation system in the form of vectored slipstream or circulation control is employed on the wing, the changes which take place in the boundary layer will no doubt allow location of the spoiler

slot closer to the trailing edge. Such a system would be extremely responsive to high angles of attack, and since lateral control is definitely critical in the VTOL and STOL craft now under study, further investigation into the use of the spoiler in a high lift blowing system should be considered.

A second limitation upon these two dimensional test lies in the application of the results to thin wings. It is probable that the chordwise location will be critically dependent upon the flow at high angles of attack, and it is possible that a more forward location will be necessary to satisfy control requirements during takeoff and landing.

4. Effect of θ

As has been mentioned, early smoke tunnel studies showed that for $\theta = 30^\circ$, a small bubble appeared aft of the blowing slot for low C_{μ} 's, indicating a reattachment of the jet and a corresponding reenergizing of the boundary layer. As C_{μ} was increased, the "bubble" elongated until the wing stalled abruptly.

It was decided to limit investigation of θ to the range of 45° to 90° degrees. Intuitively, blowing at a θ greater than 90° will approach a condition of tangential blowing on the upper surface, a means of increasing lift, and is only of importance if the spoiler jet is to be rotated to a position where lift increases are desired, as might be the case in a differential control system.

Subsequent smoke tunnel studies proved that the angle of the jet can vary from 45° to 60° degrees with good results. An angle of 60° was decided upon as offering the highest relative efficiency throughout the range of testing. Although the blowing effectiveness is somewhat lower than that of $\theta = 45^\circ$ at very low C_{μ} 's, above a value of .04 effectiveness is somewhat higher. (See Figs. 20 to 22).

5. Effect of Flap Deflection

Compared to the other parameters studies, δ_f is of secondary importance. Reference to Figs. 24 and 25 shows that the effects are erratic, and often negligible. In most cases there was a slight fall off in effectiveness as the flap angle is increased, though the effect at low C_{μ} 's can be different from that at high C_{μ} 's. There is no doubt that the condition of the boundary layer on the upper wing surface is affected by flap deflection, and it can be expected that some shift in the optimum spoiler location along the chord will be experienced in going from a clean wing to full flap. This effect will be magnified by any circulation control system employed during landing. Within the limits of this report, however, the flap, operating within a separated region at moderate C_{μ} 's, can be deflected through considerable angles without seriously impairing the spoiler effectiveness.

6. Effect of Flap Configuration

On the basis of the data represented by Fig. 26, there is no reason to limit the applicability of the spoiler to specific flap types. For slotted, double slotted, and split types there is no large difference in efficiency. This is fortunate in that other specifications on the landing performance of the aircraft will no doubt dictate the type of flap used.

Due to the high $C_{L/C}$ of some of the new vectored slipstream designs, some effort was directed toward determination of the influence of flap chord to wing chord on spoiler efficiency. As can be seen in Fig. 27, there is a rapid fall off in performance as the flap chord is increased, and it is desirable from the standpoint of jet spoiler control to limit the $C_{L/C}$ to .3.

7. Momentum Contribution of the Spoiler

As previously stated, the force contribution to the profile due to the isolated jet is by definition equal to C_μ . Therefore,

$$-\Delta C_{Lm} = C_\mu \cos \theta$$

The momentum contribution to pitching moment is then

$$\Delta C_{m_m} = \frac{x}{c} C_\mu \sin \theta$$

where x is the distance from the slot to the a.c. of the section. The values for these coefficients are given in Fig. 28.

8. Pitching Moment

Although only limited studies were made (by determining the centroid of the pressure distribution) it appears that for spoiler at .65c, there is only a slight nose down (negative) moment about the a.c. with C_μ . (See Fig. 29). It is felt, however, that the problem becomes more acute as the spoiler is moved farther aft, and recent work on the jet flap indicates excessive moments for trailing edge blowing (Ref. 14). Since for a spoiler these moments are positive, there is some position between .65c and the trailing edge where moment increments will be minimized.

On the basis of the wind and smoke tunnel tests, the prediction curves (Figs. 30 to 33) were prepared for prediction of spoiler effects on an NACA 23015 airfoil. The critical region of these curves can be seen to be in the C_μ range from 0 to .025. (It should be remembered that this data is for unsealed slotted flap, hence the slightly positive lift increments in this C_μ range). For the highest Reynolds Number tested, (1.08×10^6) , considerably greater lift reductions were experienced than in the other two series of tests. The results have been verified several times, and it appears that a critical RN might have been reached where the spoiler exercises greater control over separation of the flow. It should be remembered that the PH of

the flights tests mentioned in the next section varies from 3.2×10^6 to 4.4×10^6 . The effect of the large RN on spoiler effectiveness has not yet been ascertained in the wind tunnel.

VIII. Extension of Data to Three Dimensional Flow

Under the present contract a model is now under construction which will enable force tests to be run on a scale half panel of the L-21 wing. Attention will be directed primarily to the optimum spanwise location, and the attempt will be made to correlate 2-D smoke tunnel data, 3-D force data, and flight test data in an effort to reach general conclusions as to the possibility of predicting the effectiveness of jet spoiler control on arbitrary plan forms, as well as to establish the value of the system on light liaison type aircraft.

In an effort to check the value of these two dimensional tests, a rough calculation was made for the rolling moment due to spoiling of the flow on an L-21 wing. In (Ref. 16) T. E. Sweeney gives preliminary results for a blowing system which directed air at a θ of 45° , an X of .74, and this data plotted in Fig. (34). Despite the differences between the two airfoils, agreement is satisfactory. At the present time a modified blowing system is under consideration which will enable higher C_{M} 's to be reached on the airplane. It is interesting that Sweeney's data establishes the feasibility of using ram air power for emergency operation, for he found control to quite adequate under that condition.

IX. Conclusions and Recommendations

Two dimensional tests indicate that the jet spoiler has possible application for a variety of wing flap combinations as a form of lateral control. No critical ranges of operation were observed which could not, with careful design, be eliminated. Some investigation into the effect of Reynold's number, as well as the interaction between lift augmentation and jet spoiler systems, is recommended.

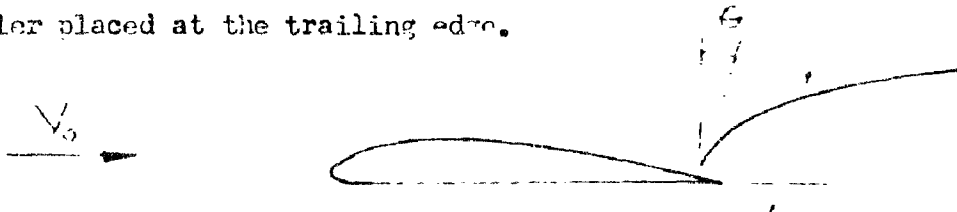
The most important parameters from the standpoint of designing a jet spoiler control for a particular wing are \bar{x} and θ . These parameters interact, and their optimum values are directly dependent upon the angle of attack range through which the spoiler is to be operated. The jet spoiler, by magnifying aerodynamically a purely momentum affect, can be a powerful means of altering lift on a wing utilizing a relatively low power blowing system.

X. APPENDIX

The Analytical Problem

Fluid separation has long been a phenomena incapable of being analyzed theoretically with any accuracy. This can be attributed to the many variables attached to any viscous flow over an airfoil. Some thought has been given, however, to the possibility of extending small perturbation airfoil theory to two dimensional airfoils from which is directed an infinitely thin sheet of high velocity air.

Malavard (in Ref. 14) has had good agreement between test data for a trailing edge "jet flap" and a theoretical analysis based upon a linearized potential theory. This configuration is identically an inverted jet spoiler placed at the trailing edge.



Malavard finds the solution of the lift equation to be of the form

$$\Delta C_L = [f(C_M) + C_M] \cos \theta$$

Such a solution follows intuitively from the nature of the flow picture about the airfoil. Since the assumption is made that the jet is concentrated to a thin sheet, it is in effect a solid extension of the profile, and the aerodynamic effect of the spoiler on the circulation of the section can be separated from the momentum transfer within this sheet. The latter becomes, in effect, merely a line of velocity discontinuities.

Solving the potential harmonic function by an electrical analogy, Malavard finds $f(C_M) = \frac{4 V_{TE}}{V_0 C}$, V_{TE} corresponding to the potential of the flow at the trailing edge. Comparing his prediction to test data, one finds that the curve can be approximated by $1.5 \sqrt{C_M}$, the value

for the constant B in the case cited being 3.9. Although this result is restricted to small angles of attack and particularly to a trailing edge jet, it is interesting to note Fig. 13 where ΔC_L is linear with $\sqrt{C_{\mu}}$ for a plain wing. On the basis of this data, it is felt that an equation of the form

$$-\Delta C_L = [B_1 + B_2 \alpha^2] \sqrt{C_{\mu}} \quad B_1, B_2 = \text{constants}$$

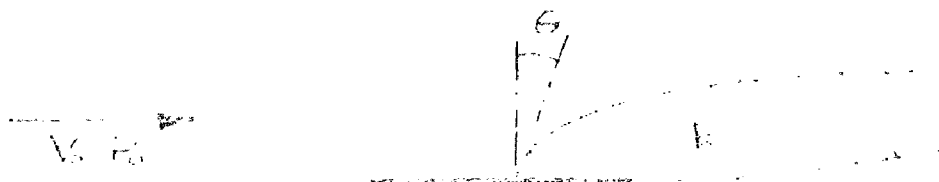
represents these curves for spoiler locations aft of the mid-chord point.

The major difficulty with this generalization appears at low C_{μ} 's, for the linearization does not hold in this region. The alternative is to adjust the equation to the point of intersection with the x axis. Then,

$$\Delta C_L = [B_1 + B_2 \alpha^2] \sqrt{C_{\mu}} + \Delta C_{L_0}$$

where ΔC_{L_0} is a function of α and represent this intersection (valid only for $C_{\mu} > 0$.) This equation is helpful only from the standpoint of indicating a possible form of the solution, based entirely on experimental work.

As might be expected, the prediction of jet spoiler effectiveness at stations forward of the trailing edge is much more complicated than the case treated by Malavard, due to the existence of a region of separation. The only approach which appears at this time to have merit considers the flow near the jet to act as a free streamline on the upper surface of a region of "dead air" at free stream static pressure. The lower boundary is also a free streamline from the trailing edge.



Knowing that the curvature of the jet is determined by the pressure differential across it, and linearizing the flow by limiting it to small perturbations, one is able to connect the potential along the upper surface of the jet to its derivative.

$$\phi = \phi'_y \frac{C_{\mu} c}{2} + \bar{\phi}(y) \quad \bar{\phi} \text{ constant}$$

This establishes only a portion of the boundary of the flow. Although the detailed calculations have not been carried out at this time, it appears that it might be possible to establish sufficient boundary conditions for an electrical analogy. The major approximation, that of the existence of free stream static pressure within the area bounded by free streamlines, is considerably in error as actually this pressure is much lower. This fact, together with other assumptions, would probably limit the use of the results of such a calculation, and it is felt that experimental verification would still remain necessary before adaption of the jet spoiler to a particular lifting surface could be considered.

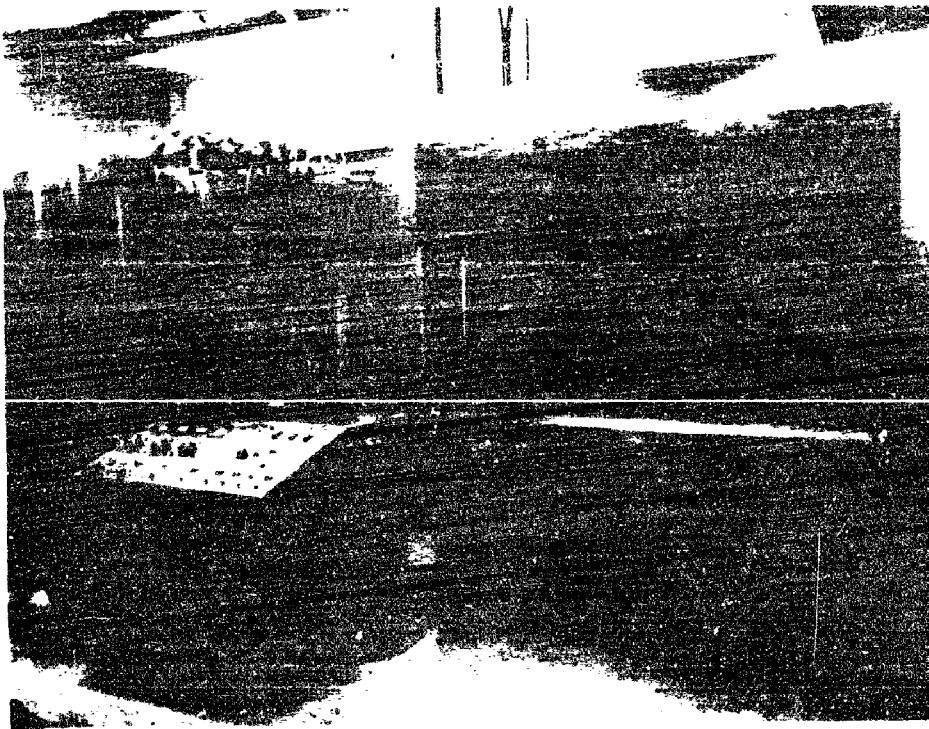
XI. REFERENCES

1. Ashkenas, I. L.: The Development of a Lateral Control System for Use with Large Span Flaps, NACA TN 1015, January, 1946.
2. Young, A. D.: Lateral Control with High Lift Devices, R. and M. No. 2583, 1951.
3. Lowry, J. G., and Liddell, R. B.: Wind-Tunnel Investigations of a Tapered Wing with a Plug-Type Spoiler-Slot Aileron and Full Span Slotted Flaps, WR L-250, July, 1942.
4. Rogallo, F. M., and Swanson, R. S.: Wind-Tunnel Development of a Plug-Type Spoiler-Slot Aileron for a Wing with a Full-Span Slotted Flap and a Discussion of its Applications, WR L-420, November, 1941.
5. Jones, A. L., Lamb, O. P., and Cronk, A. E.: A Method for Predicting the Lift Effectiveness of Spoilers at Subsonic Speeds, Journal of the Aeronautical Sciences, April, 1956.
6. Weick, F. E., Soule, H. A., and Gough, M. N.: A Flight Investigation of the Lateral Control Characteristics of Short Wide Ailerons and Various Spoilers with Different Amounts of Wing Dihedral, NACA Report 494, 1934.
7. Wenzinger, C. J., and Rogallo, F. M.: Wind-Tunnel Investigation of Spoiler Deflector, and Slot Lateral-Control Devices on Wings with Full-Span Split and Slotted Flaps, NACA Report 706, 1941.
8. Coleman, W. S., and Tibbory, G. H.: Some Wind-Tunnel Developments of the Spoiler as a Form of Lateral Control, R. and M. No. 2586, 1951.
9. Kerr, C. E.: Flight Tests on a Falcon with Spoiler Lateral Control, R. and M. No. 2491, 1950.
10. Soule, H. A., and McAvoy, W. H.: Flight Investigation of Lateral Control Devices for use with Full-Span Flaps, NACA Report No. 517, 1935.
11. Harris, T. A., and Lowry, J. G.: Pressure Distribution over and NACA 23021 Airfoil with a Slotted and a Split Flap, NACA Report No. 718, 1941.
12. Theodorsen, T., and Garrick, I. E.: General Potential Theory of Arbitrary Wing Sections, NACA Report No. 452, 1933.
13. Knowlton, M. P.: A Theoretical Investigation on the Determination of Lift Coefficients in Two-Dimensional Smoke Tunnels, Princeton University Report No. 289, March, 1955.
14. Malavard, L., Poisson-Quinton, Ph., and Jousseranlot, P.: Theoretical and Experimental Studies of Circulation Control. Translation by Berthoff, T. M. and Hazen, D. C., Princeton University Report No. 358, July, 1956.
15. Sweeney, T. E.: Basic Control Characteristics of the L-21 Airplane. Princeton University Report No. 287, February, 1954.

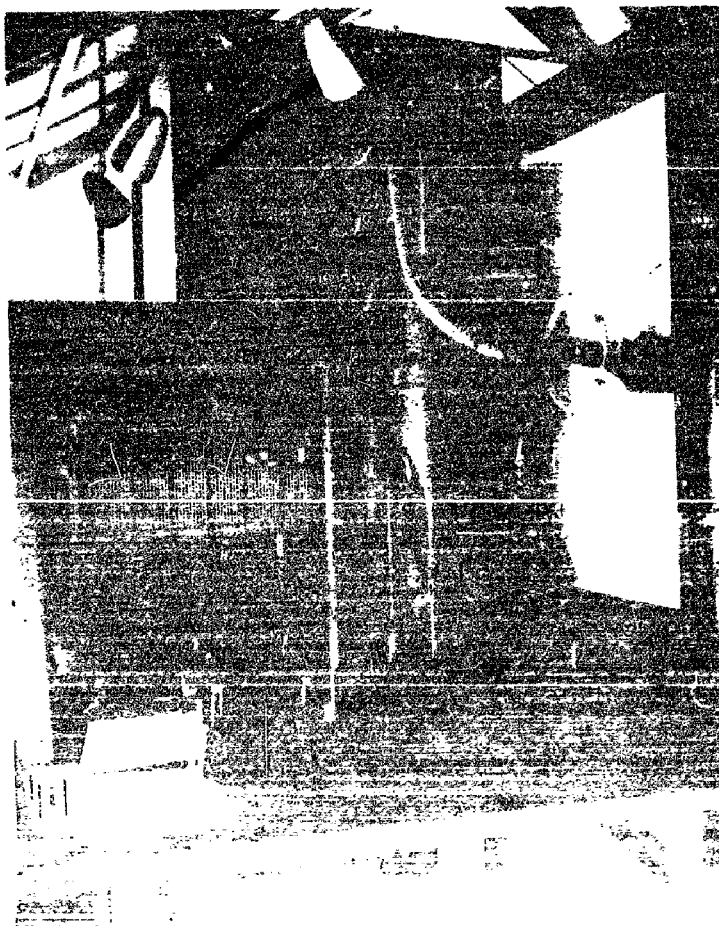
16. Sweeney, T. E.: Preliminary Full Scale Measurements of Jet Spoiler Performance on the L-21 Airplane, Princeton University Report No. 291, March, 1955.
17. Powell, D. G.: Full Scale Pressure Distribution Investigation of a Jet Spoiler on the L-21 Airplane, Princeton University Report No. 308, June, 1955.
18. Lowry, J. G., and Turner, T. R.: Low-Speed Wind-Tunnel Investigation of a Jet Control on a 35° Swept Wing. NACA RM L53109a, October, 1953.
19. Ballentine, D. C., and Barnard, G. A.: Two-Dimensional Wind-Tunnel Tests of a Jet Type Spoiler on an NACA 64A010 Airfoil Section Equipped with High Lift Devices. DTMB.
20. Attinello, J. S.: An Air-Jet Spoiler. Navaer Report DR-1579, August, 1953.
21. Stein, H.: Guided Projectiles: Trials on Wing using Jet Methods for Increasing Lift, Unt. 329T.
22. Gothert, B.: Effectiveness of a Spoiler at High Subsonic Speeds. Reps. and Translations No. 364, British M.C.S. (A) Volkenrode, February, 1947.

Note: Though not presently available to the authors, References 21 and 22 were listed by Attinello in Reference 20 as reports of early experimentation in the jet spoiler.

CONFIDENTIAL



(a) 2"X36" TWO-DIMENSIONAL SMOKE TUNNEL

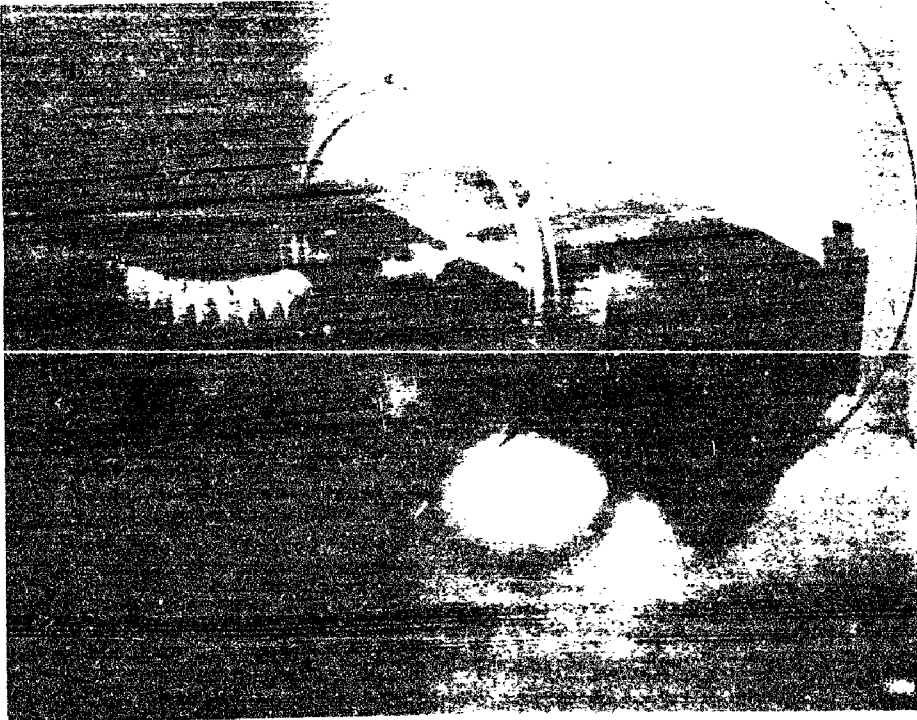


(b) TEST APPARATUS

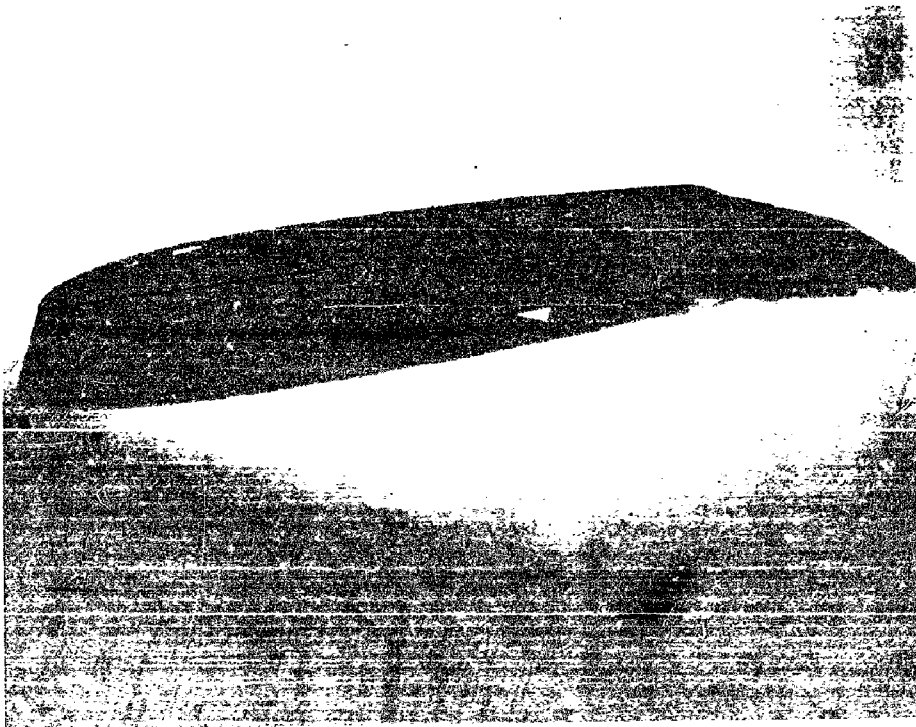
12"X48" TWO-
DIMENSIONAL
WIND TUNNEL

CONFIDENTIAL

CONFIDENTIAL

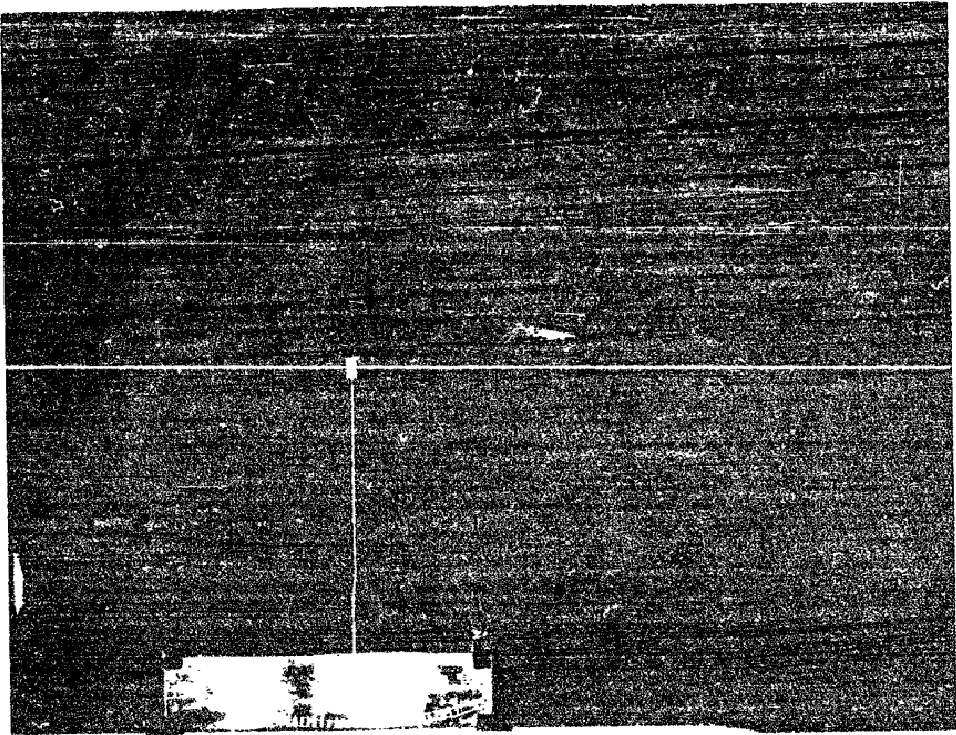


(a) 2-D WIND TUNNEL MODEL

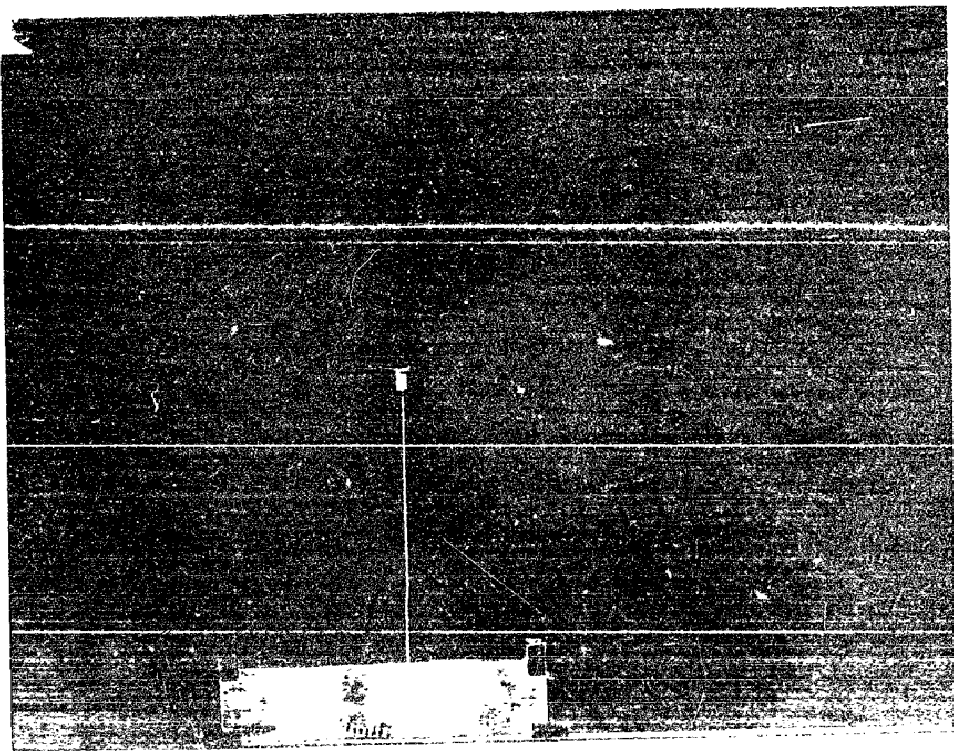


(b) 2-D FLOW VISUALIZATION MODEL

CONFIDENTIAL

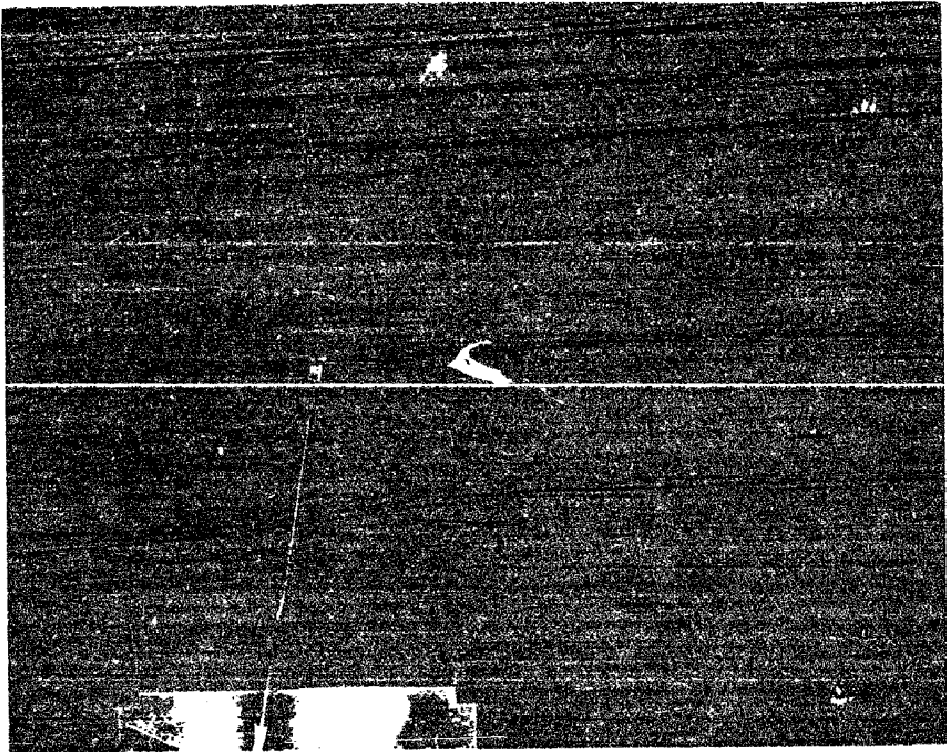


(a) PLAIN FLAP $\alpha = 0^\circ$ $\delta = 0^\circ$
 $C_\mu = 0$

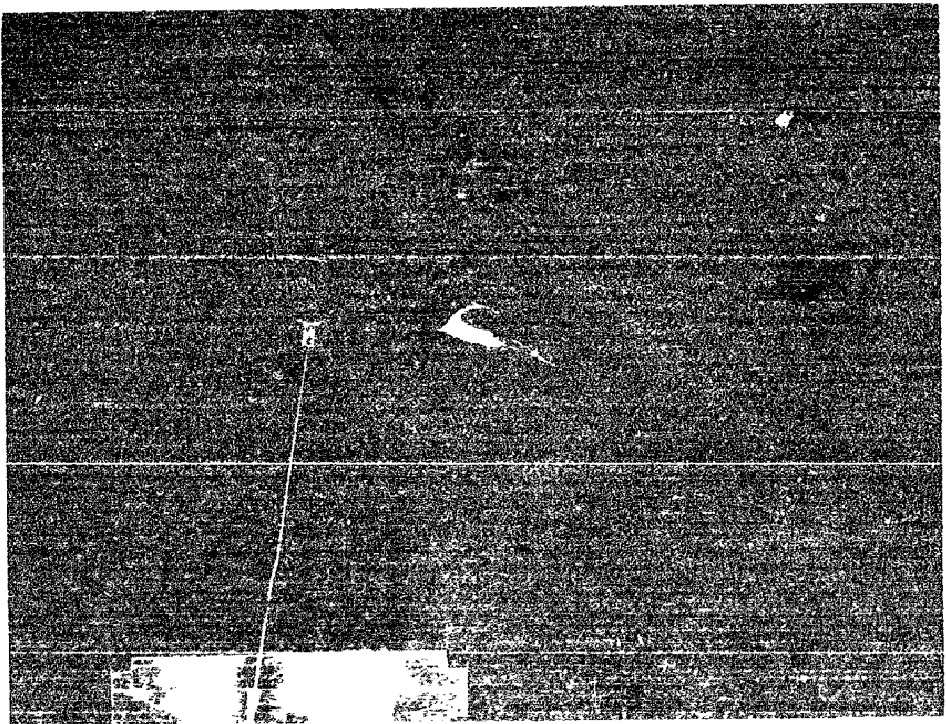


(b) PLAIN FLAP $\alpha = 0^\circ$ $\delta = 0^\circ$
 $C_\mu = .038$

CONFIDENTIAL

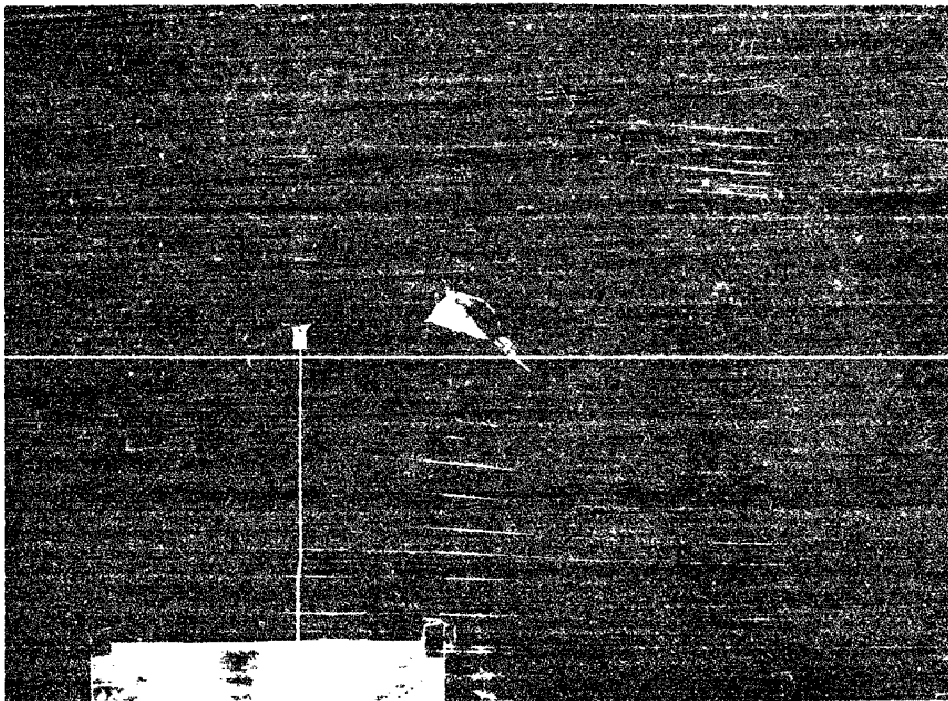


(a) SLOTTED FLAP $\alpha = 10^\circ$ $\delta = 20^\circ$
 $C_\mu = 0$



(b) SLOTTED FLAP $\alpha = 10^\circ$ $\delta = 20^\circ$
 $C_\mu = 0.075$

CONFIDENTIAL



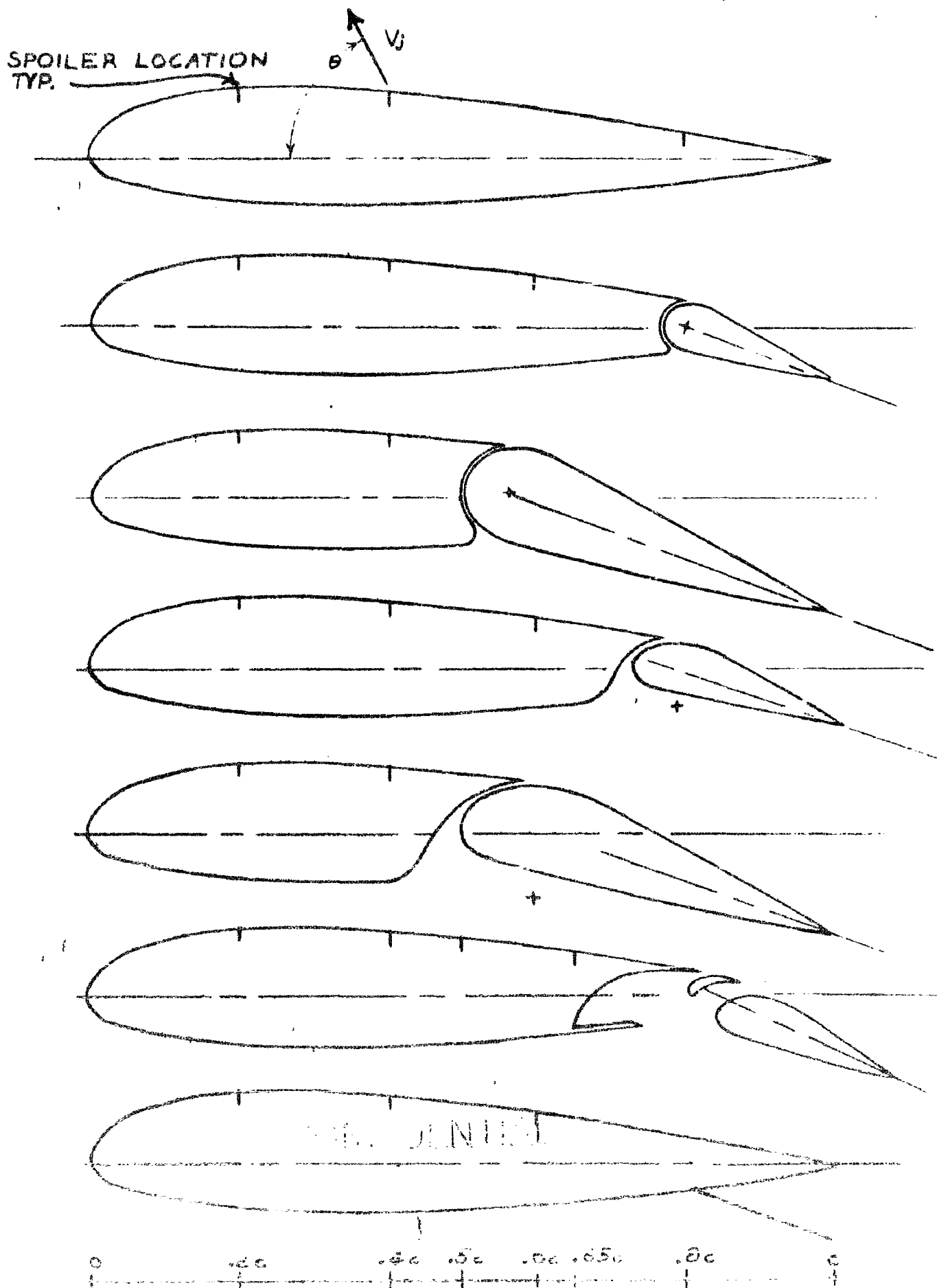
(a) $C_{\mu} = .073$ $\alpha = 0^{\circ}$ $\delta = 40^{\circ}$



(b) $C_{\mu} = .138$ $\alpha = 5^{\circ}$ $\delta = 40^{\circ}$

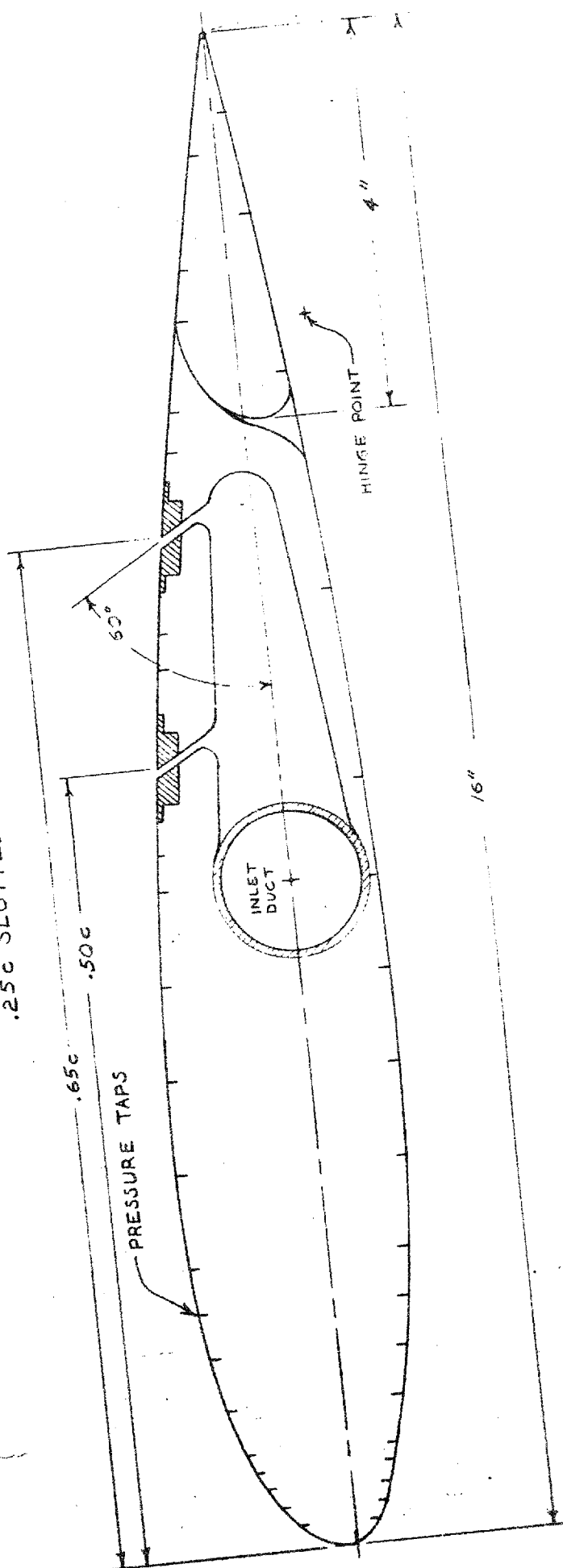
TWO DIMENSIONAL SMOKE TUNNEL MODELS

NACA 23015

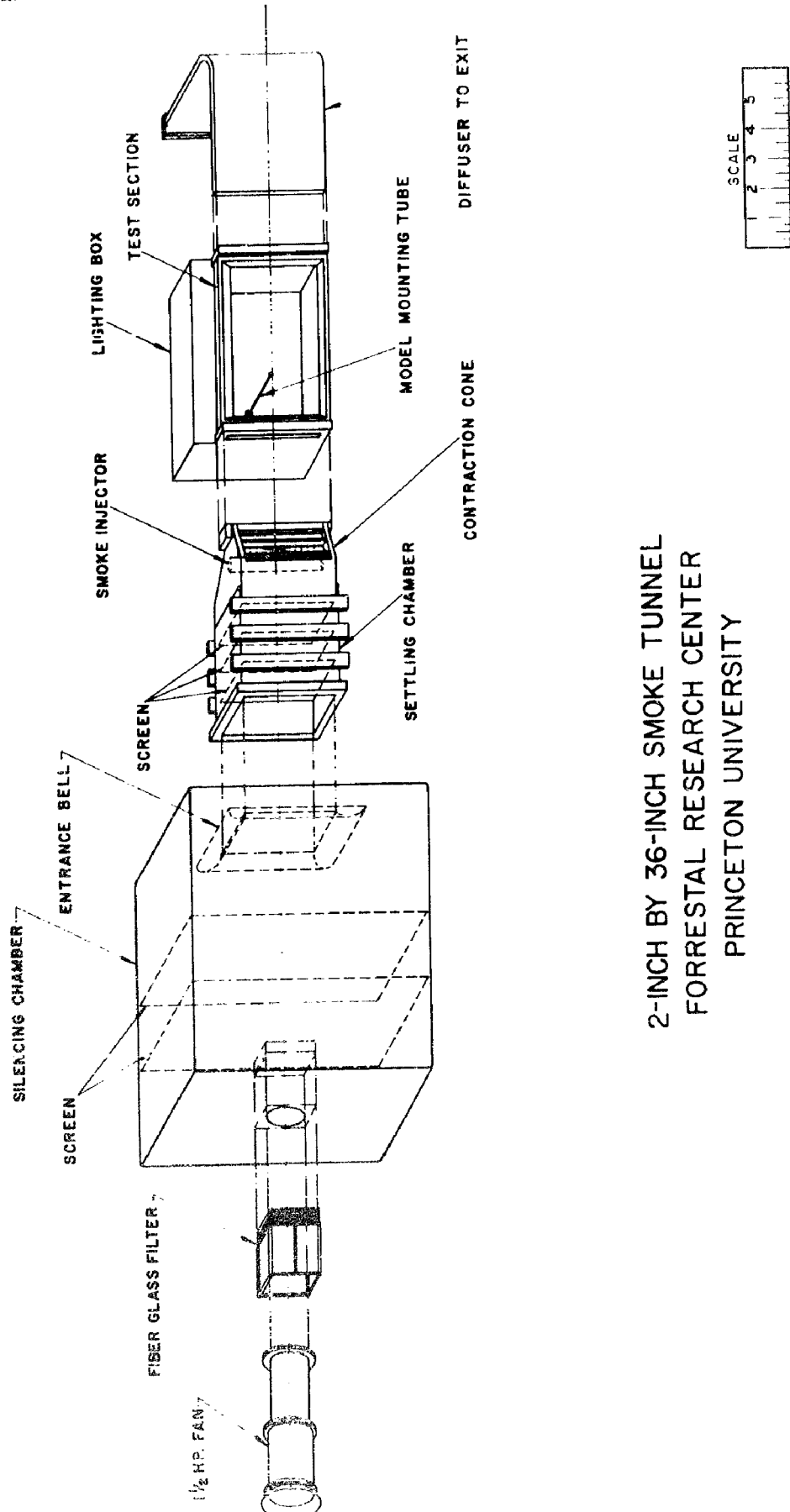


CONFIDENTIAL
TWO DIMENSIONAL PRESSURE DISTRIBUTION MODEL

CROSS SECTION
NACA 23015
.25c SLOTTED FLAP

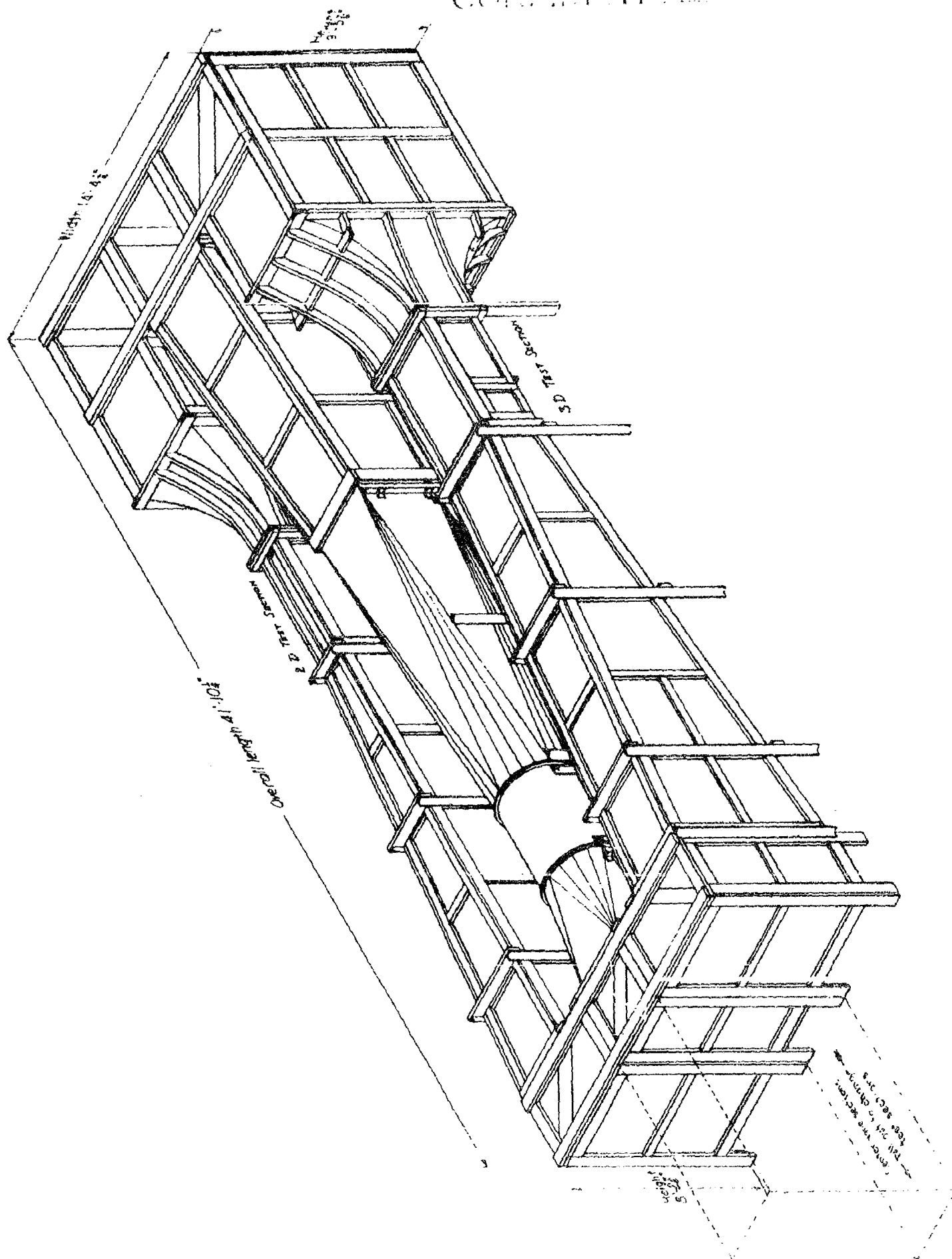


CONFIDENTIAL



2-INCH BY 36-INCH SMOKE TUNNEL
FORRESTAL RESEARCH CENTER
PRINCETON UNIVERSITY

FIG. 9



CONFIDENTIAL

NACA 23015 WITH .25c
SLOTTED FLAP

FIG. 10

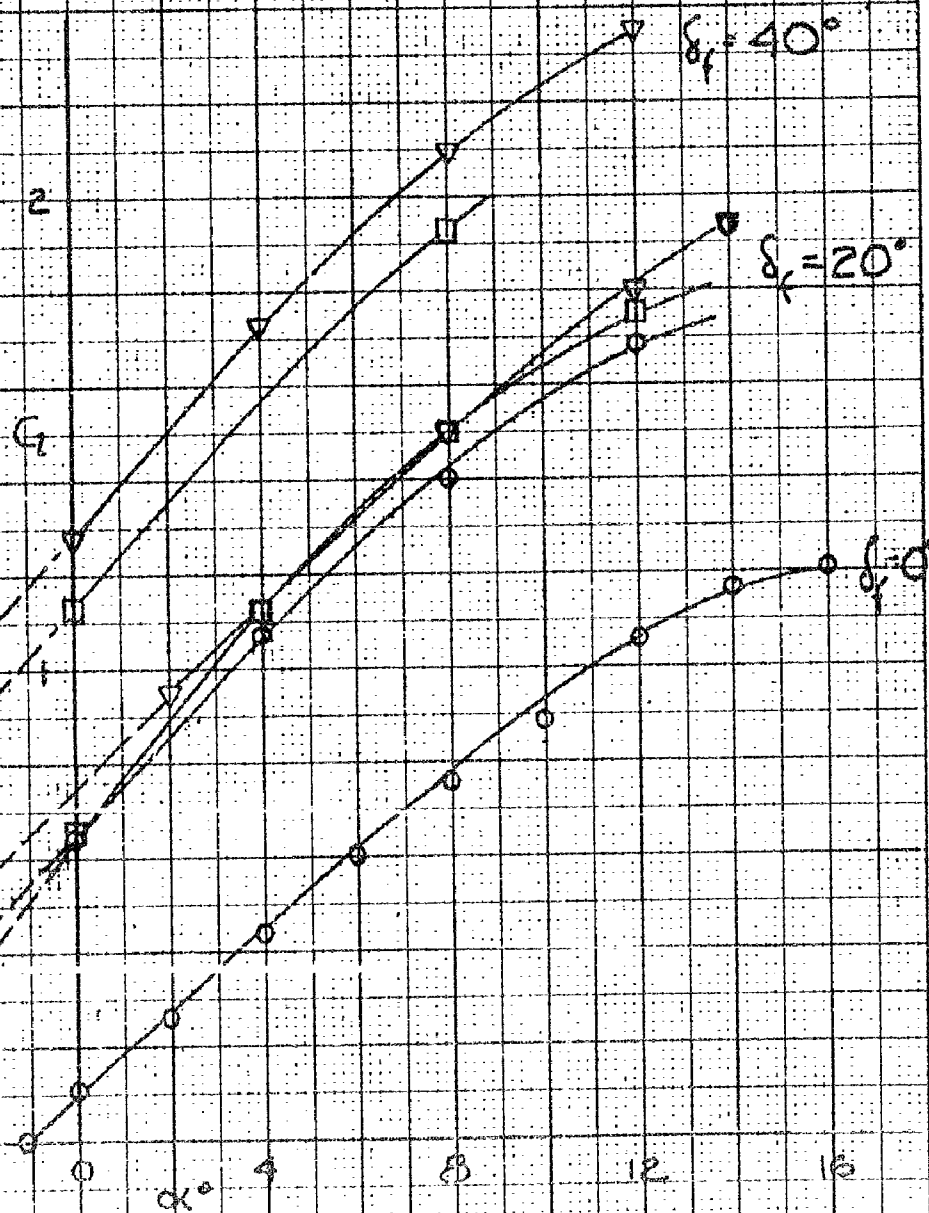
C_L VS α
FOR SEVERAL R_N

LEGEND

$\circ R_N = 2.5 \times 10^5$

$\square R_N = 5.4 \times 10^5$

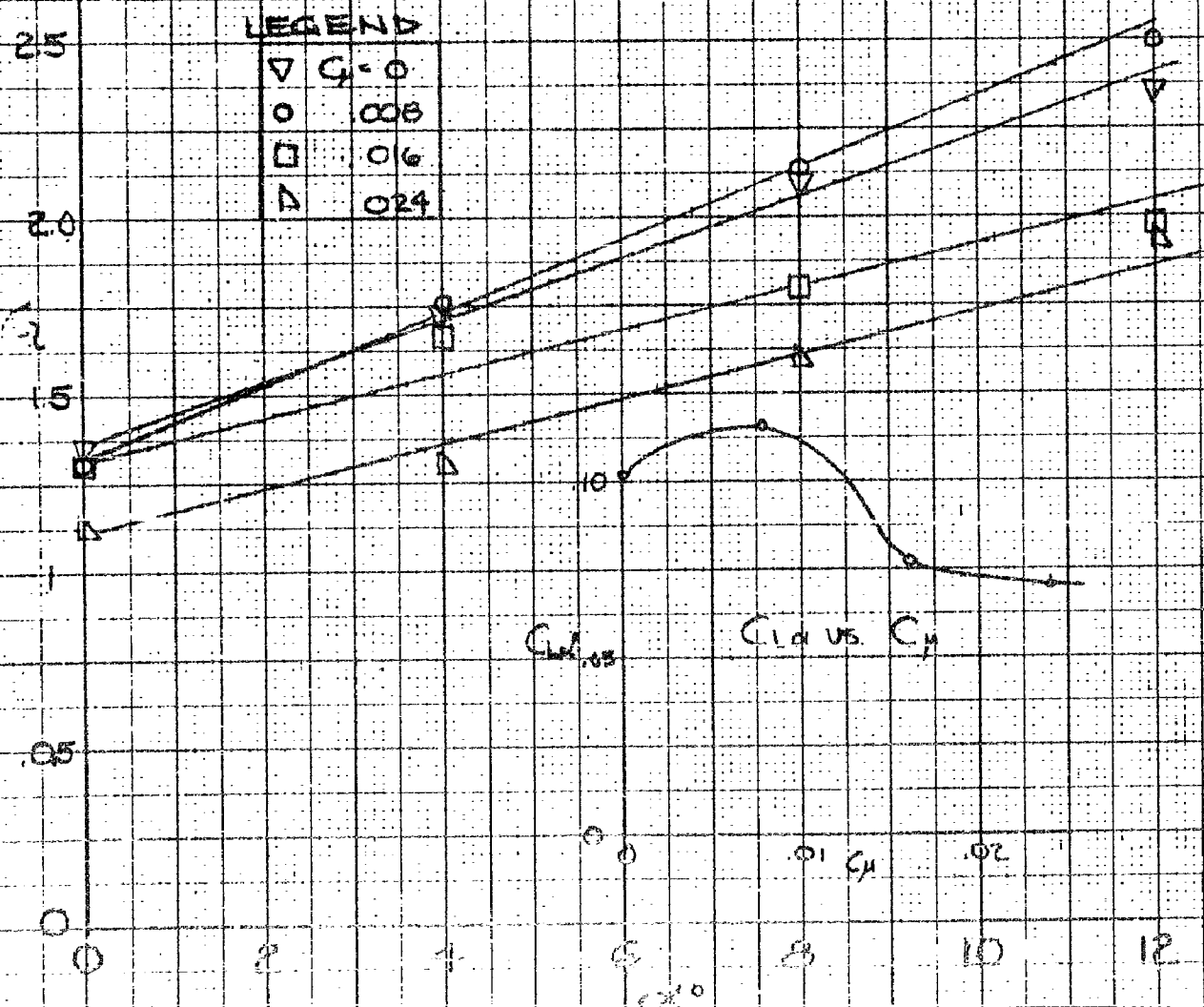
$\nabla R_N = 1.07 \times 10^6$



CONFIDENTIAL

FIG. 11

NACA 23015 WITH JET
SPOILER, .25c SLOTTED
FLAP $R_n = 1108 \times 10^4$
 $\delta_f = 40^\circ$ $\theta = 60^\circ$ C_L vs. α°



CONFIDENTIAL

FIG. 12

PLAIN WING WITH JET SPOILER

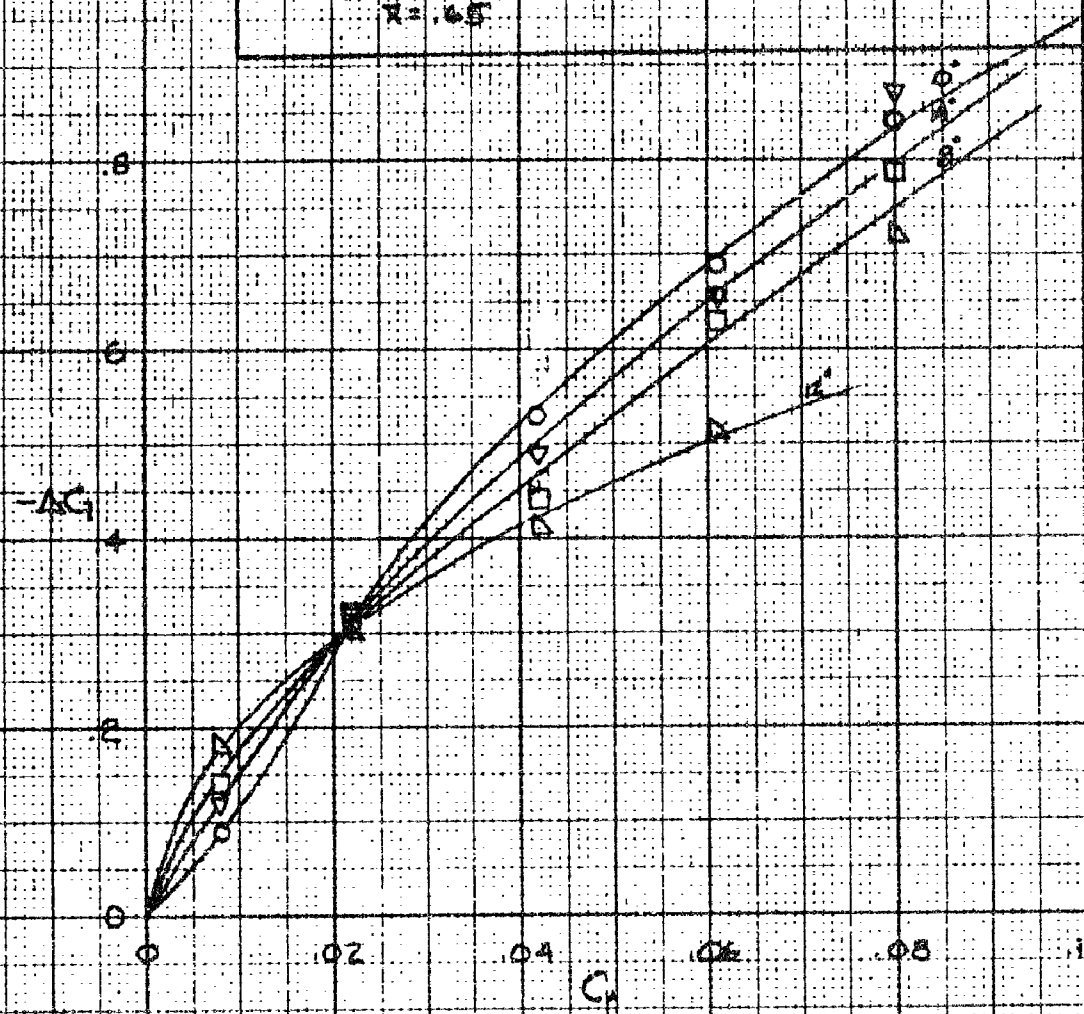
NACA 23015

2-D SMOKE TUNNEL DATA

$Re = 2.45 \times 10^6$

$\theta = 60^\circ$

$\tau = .65$



LEGEND

	θ	G_c (NACA DATA)
○	0°	.10
▽	4°	.50
□	8°	.90
△	12°	1.30

CONFIDENTIAL

FIG. 13

PLAIN WING WITH JET SPOILER

NACA 23015

Re = 2.48 x 10⁶

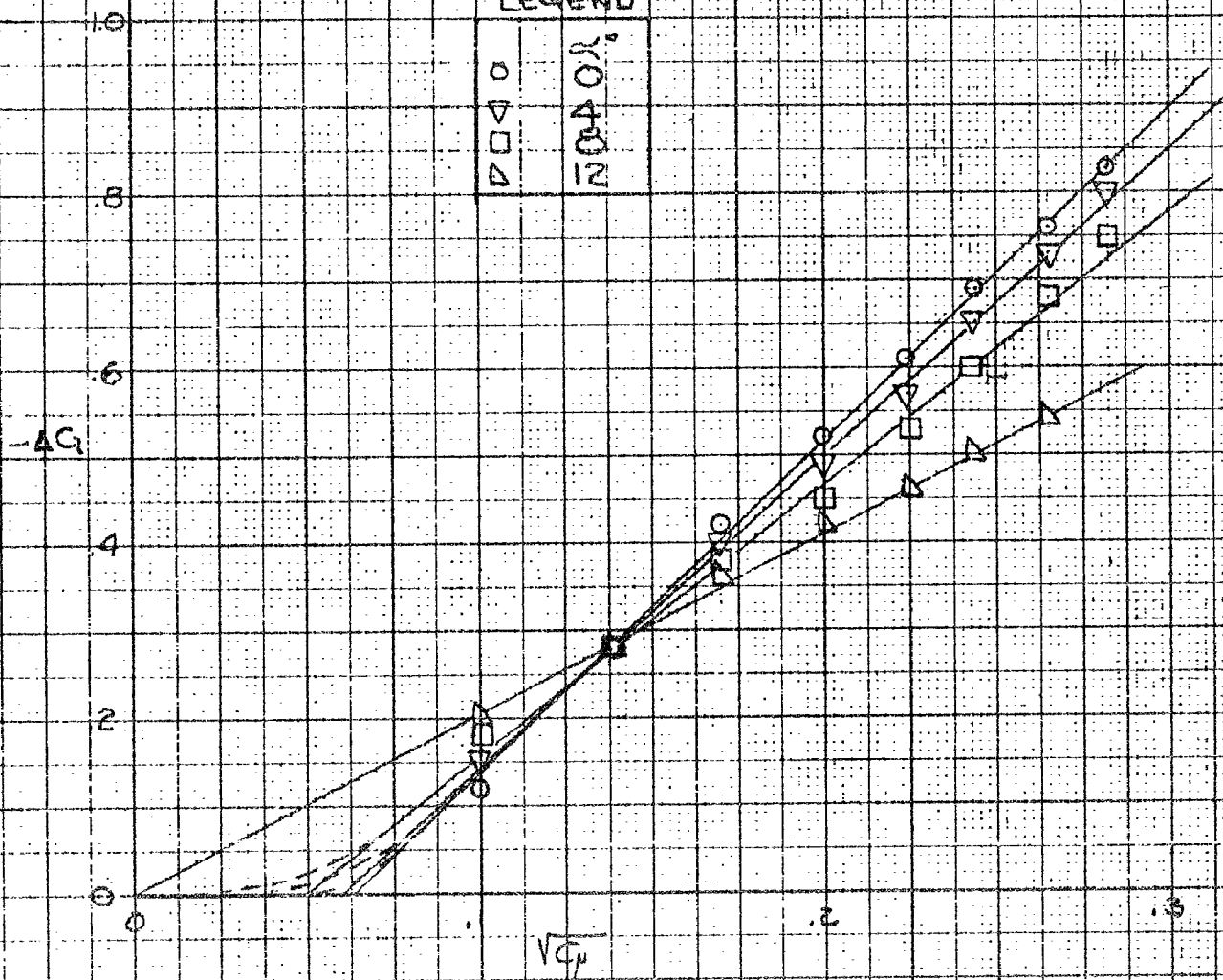
$\theta = 60^\circ$

$\bar{x} = .65$

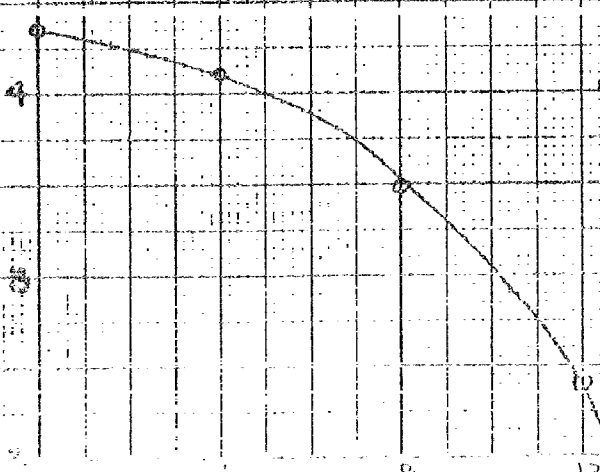
$-\Delta C_L$ vs $\sqrt{C_{p,j}}$

LEGEND

○	0%
▽	4%
□	8%
△	12%



$$B = \frac{d(-\Delta C_L)}{d\sqrt{C_{p,j}}} \text{ per } \theta$$



CONFIDENTIAL

NACA 23015 MODIFIED WITH
JET SPOILER
.25c SLOTTED FLAP $-\Delta C_l$ vs. C_p
 $Re = 2.48 \times 10^5$ $\alpha = .65^\circ$
 $\theta = 60^\circ$

FIG. 14

LEGEND

○	0%
▽	4
□	8
△	12

$-\Delta C_l$

$\delta_1 = 20^\circ$

C_p

$-\Delta C_l$

$\delta_1 = 40^\circ$

C_p

EUGENE DIETZEN CO.
MADE IN U. S. A.

NC 34) 20 DIETZEN GRAPH PAPER
20 X 20 PER INCH

CONFIDENTIAL

FIG. 15

NACA 23015 MODIFIED
 WITH JET SPOILER
 .25 C SLOTTED FLAP
 $Re = 1.07 \times 10^6$
 $\theta = 60^\circ$
 $\alpha = .65$ - ΔC_L vs C_H

LEGENDA A

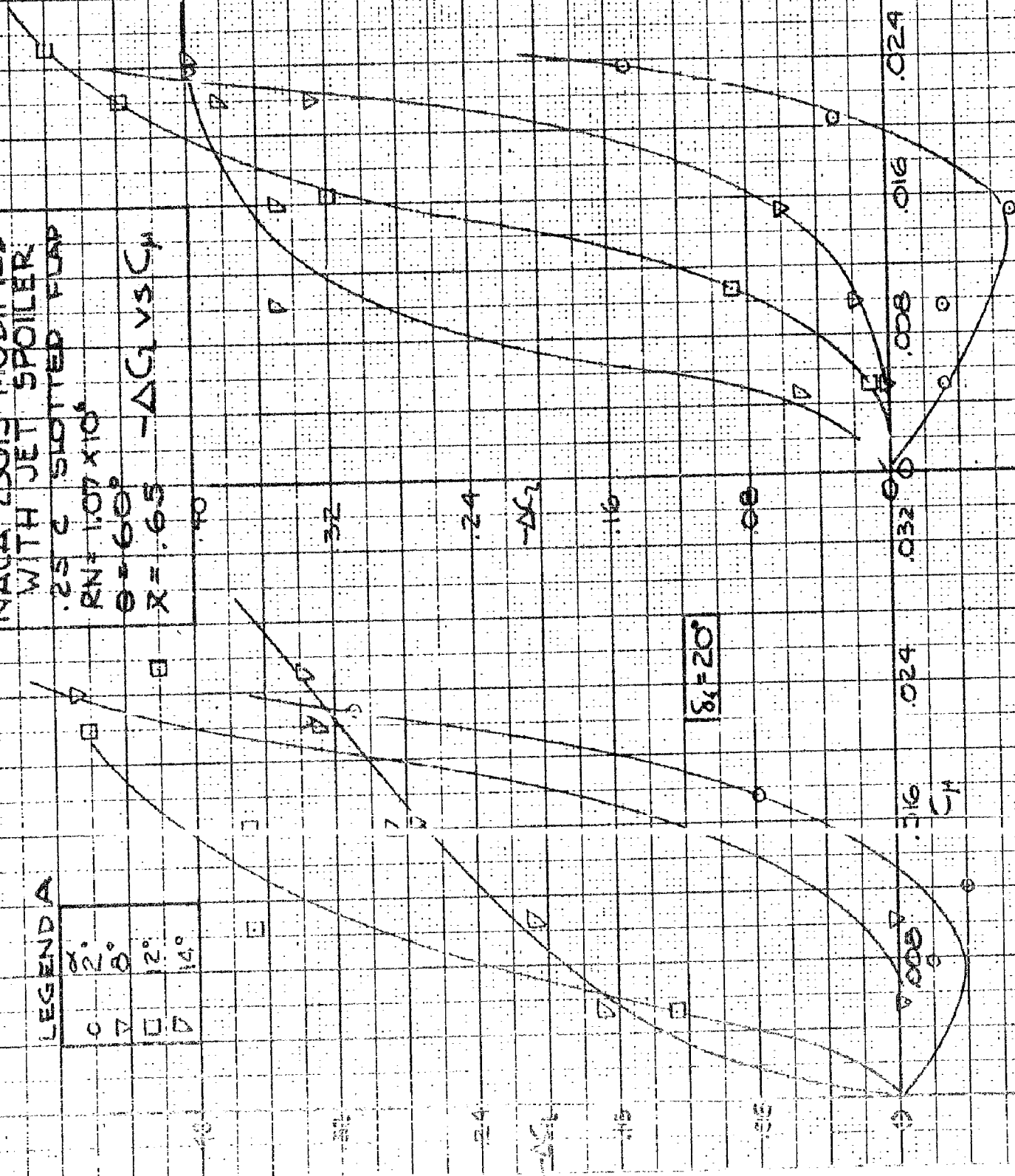
\square	2°
∇	4°
\square	6°
∇	12°
\square	14°

LEGENDA B

\square	8°
∇	4°
\square	6°
∇	12°

$\delta_1 = 40^\circ$

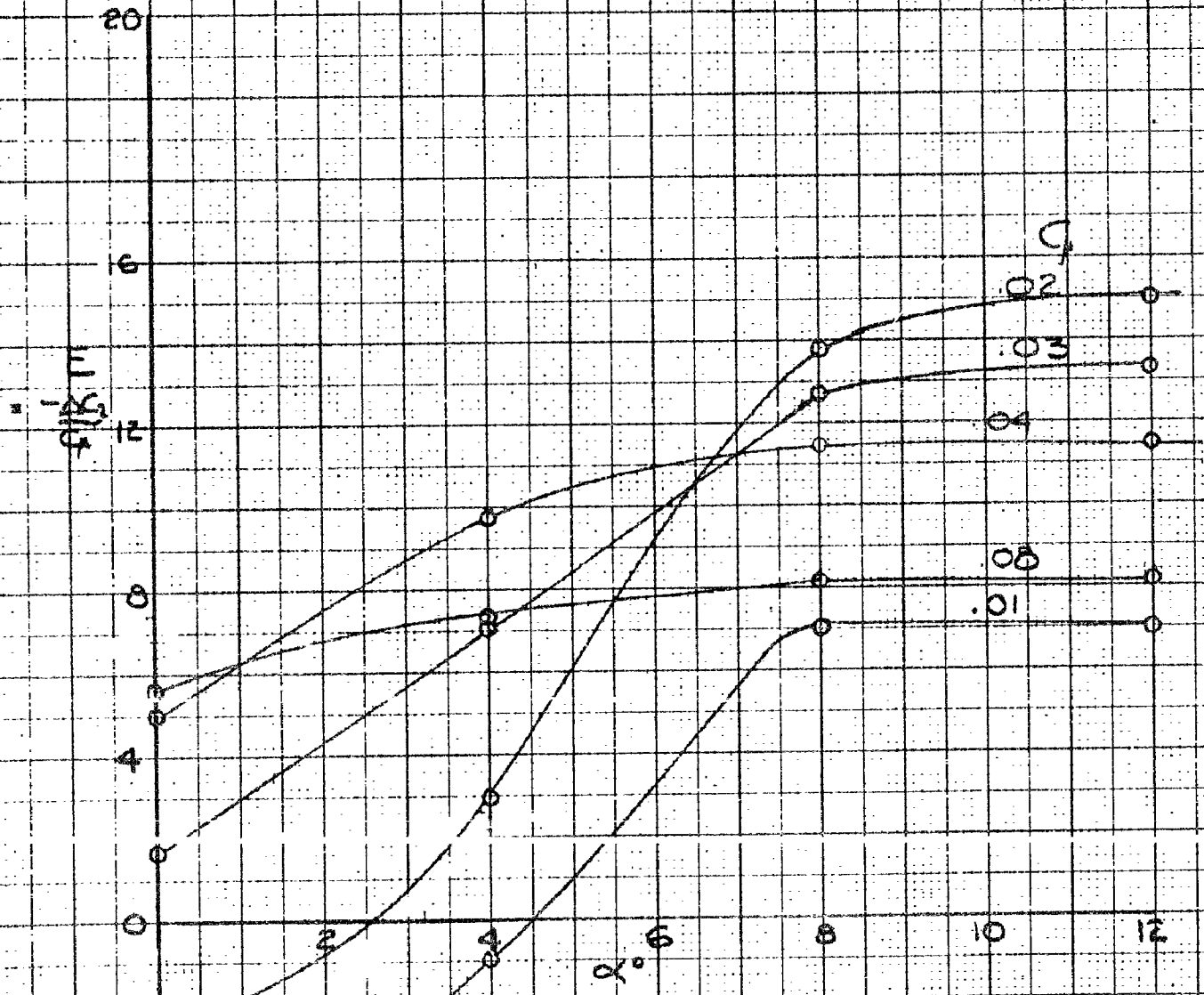
$\delta_1 = 20^\circ$



CONFIDENTIAL

NACA 23015 MODIFIED WITH
 JET SPOILER
 .25c SLOTTED FLAP
 $\theta = 60^\circ$ $\delta_f = 20^\circ$
 $\lambda = .65$ E vs α°
 $\delta_f = 20^\circ$ ($E = \frac{-\Delta C_L}{C_L}$)

FIG. 16



CONFIDENTIAL

FIG. 17

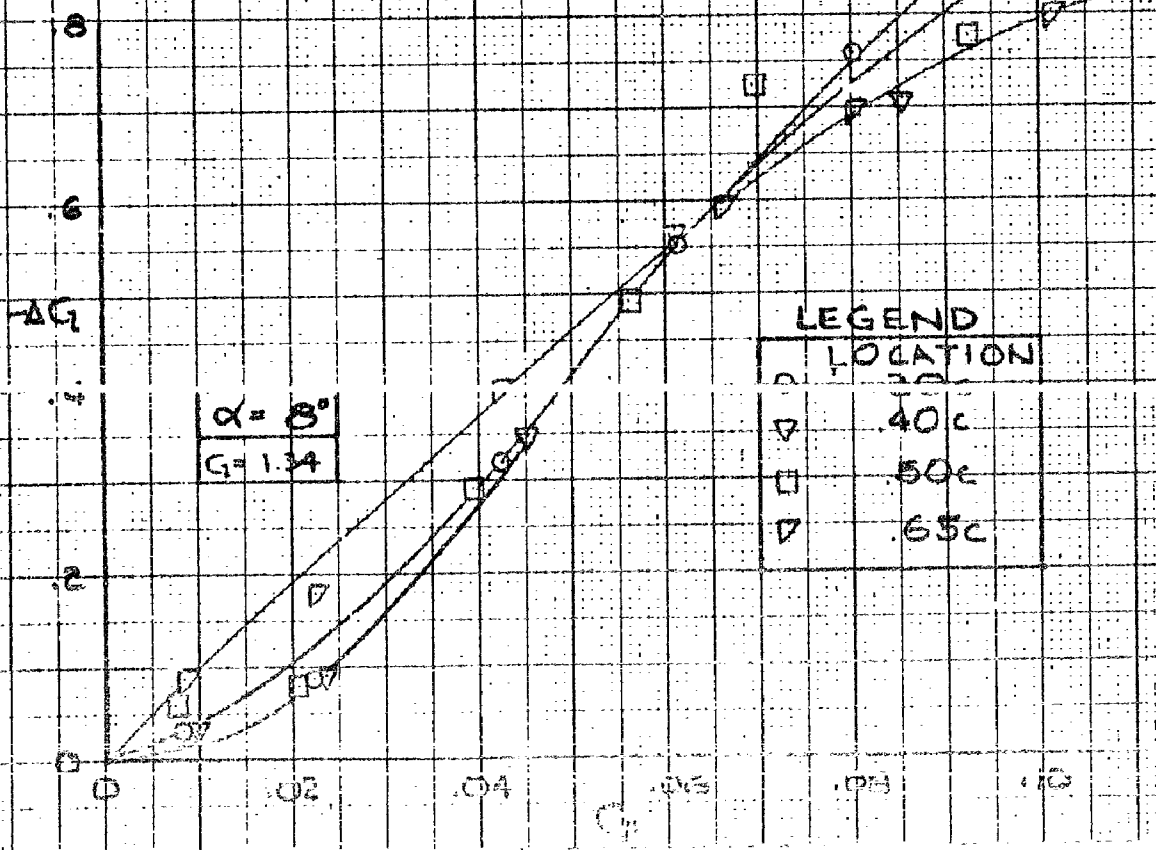
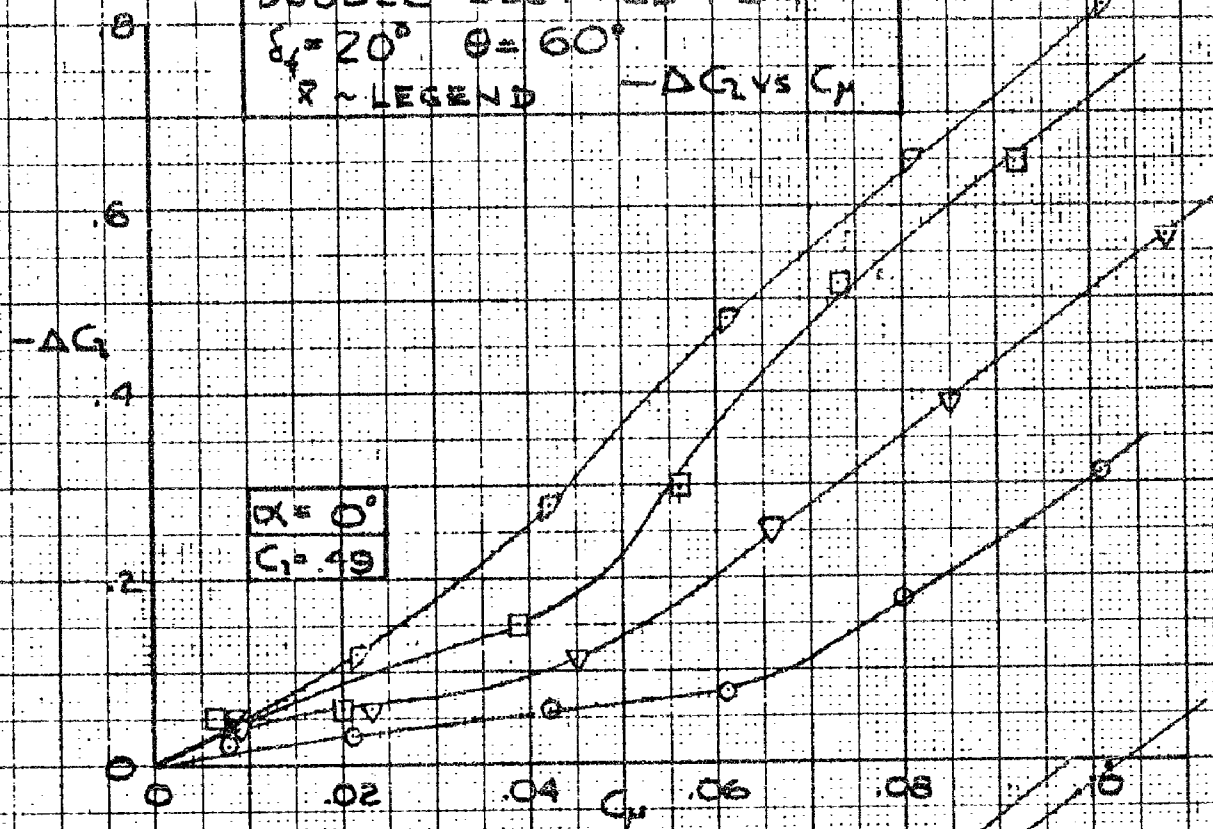
NACA 23015 MODIFIED WITH
JET SPOILER

$Re = 2.5 \times 10^6$
DOUBLE SLOTTED FLAP

$\delta_f = 20^\circ$ $\theta = 60^\circ$

α - LEGEND

$-\Delta C_L$ vs C_M

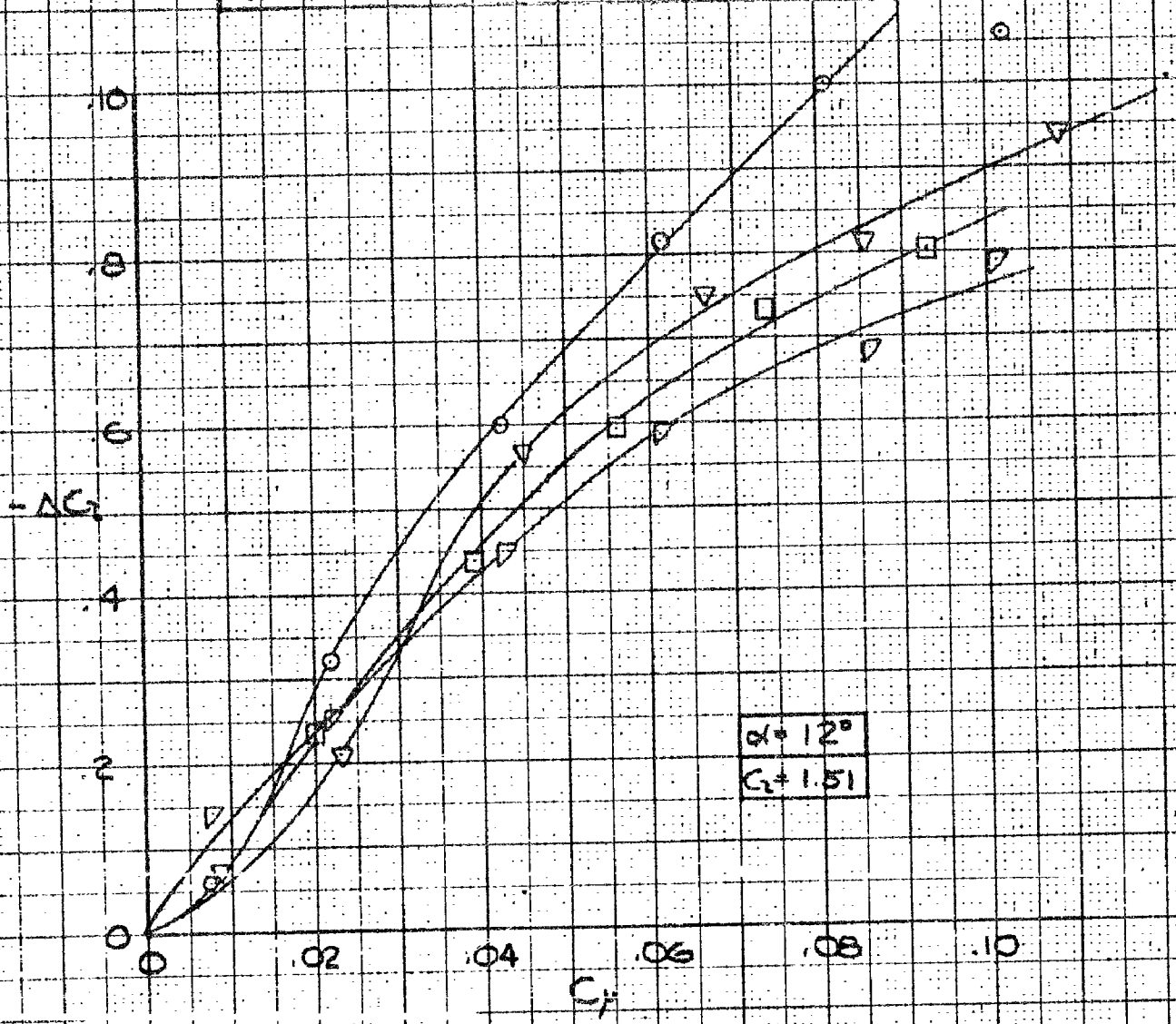


LEGEND	
LOCATION	
○	20c
△	40c
□	50c
◇	65c

CONFIDENTIAL

FIG 18

NACA 23015 MODIFIED WITH A
JET SPOILER
RN = 2.5×10^5 DOUBLE SLOTTED
FLAP
 $\theta = 60^\circ$
 $\delta = 20^\circ$
X - LEGEND



LEGEND
O LOCATION
.202
V .402
□ .502
▽ .652

CONFIDENTIAL

FIG. 19

NACA 23015 MODIFIED WITH

JET SPOILER

Re = 2.5 x 10⁶ PLAN WING

$\theta = 60^\circ$ $-\Delta C_L$ vs. α°

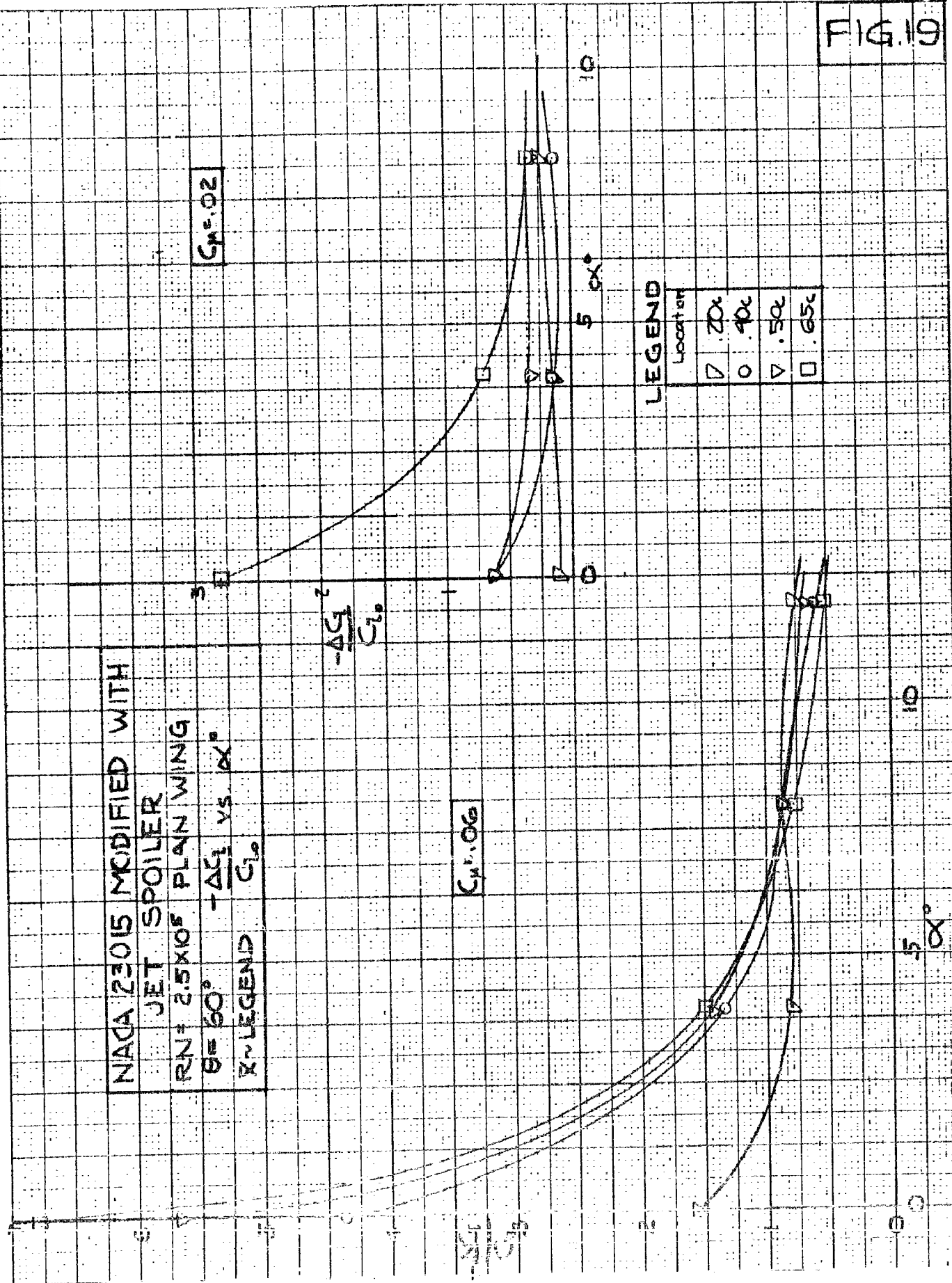
Re-LEGEND C_L

$C_M = 0.2$

$C_M = 0.06$

LEGEND

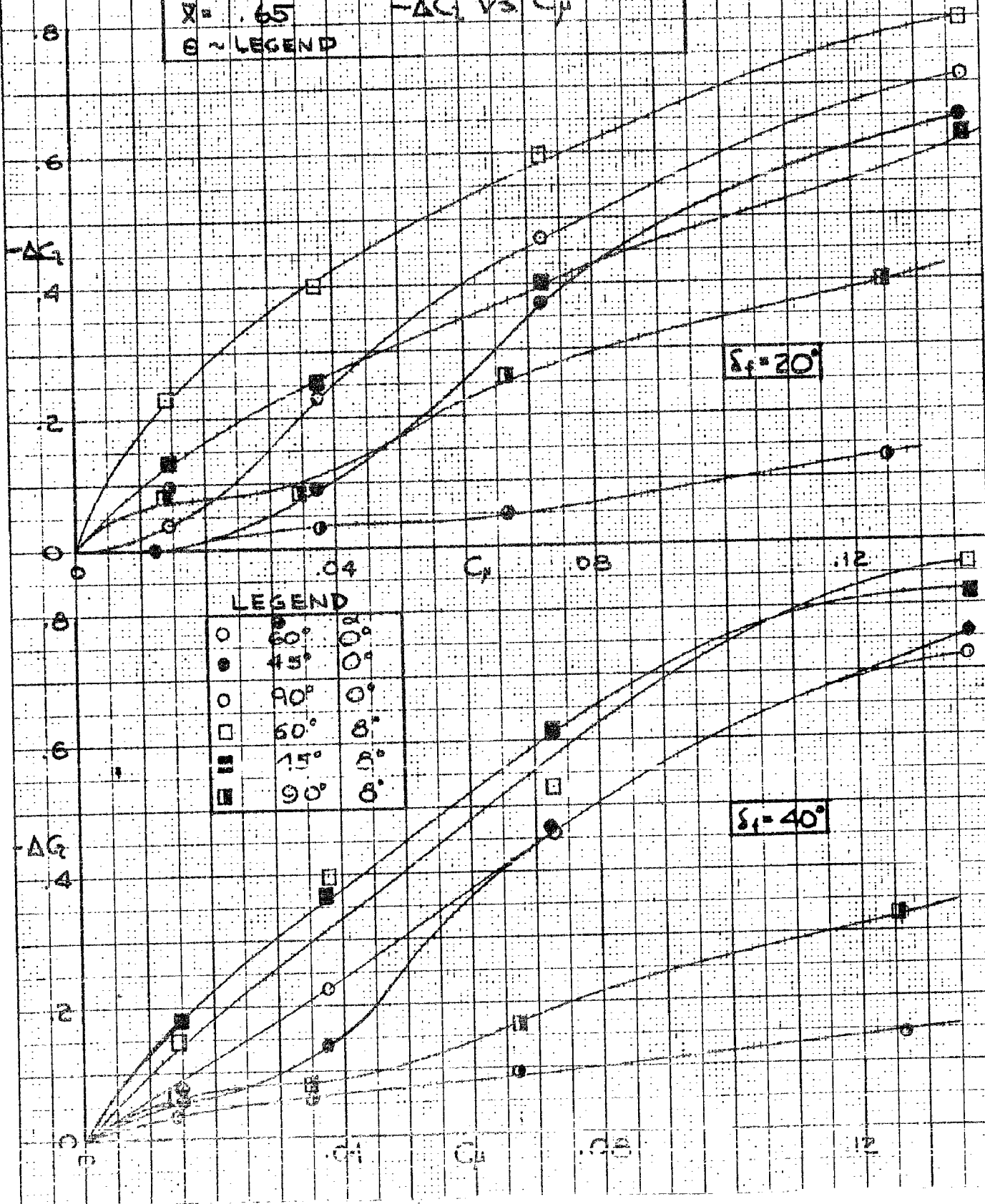
Location
∇ .20c
\circ .40c
∇ .50c
\square .65c



CONFIDENTIAL

NACA 23015 WITH JET SPOILER
 .25c SLOTTED FLAP
 $Re = 2.5 \times 10^5$
 $x = .65$
 $-\Delta C_L$ vs C_L
 $\theta \sim$ LEGEND

FIG. 20



CONFIDENTIAL

FIG 21

NACA 23015 WITH JET SPOILER

40° C FLAP (SLOTTED)

2-D SMOKE TUNNEL DATA

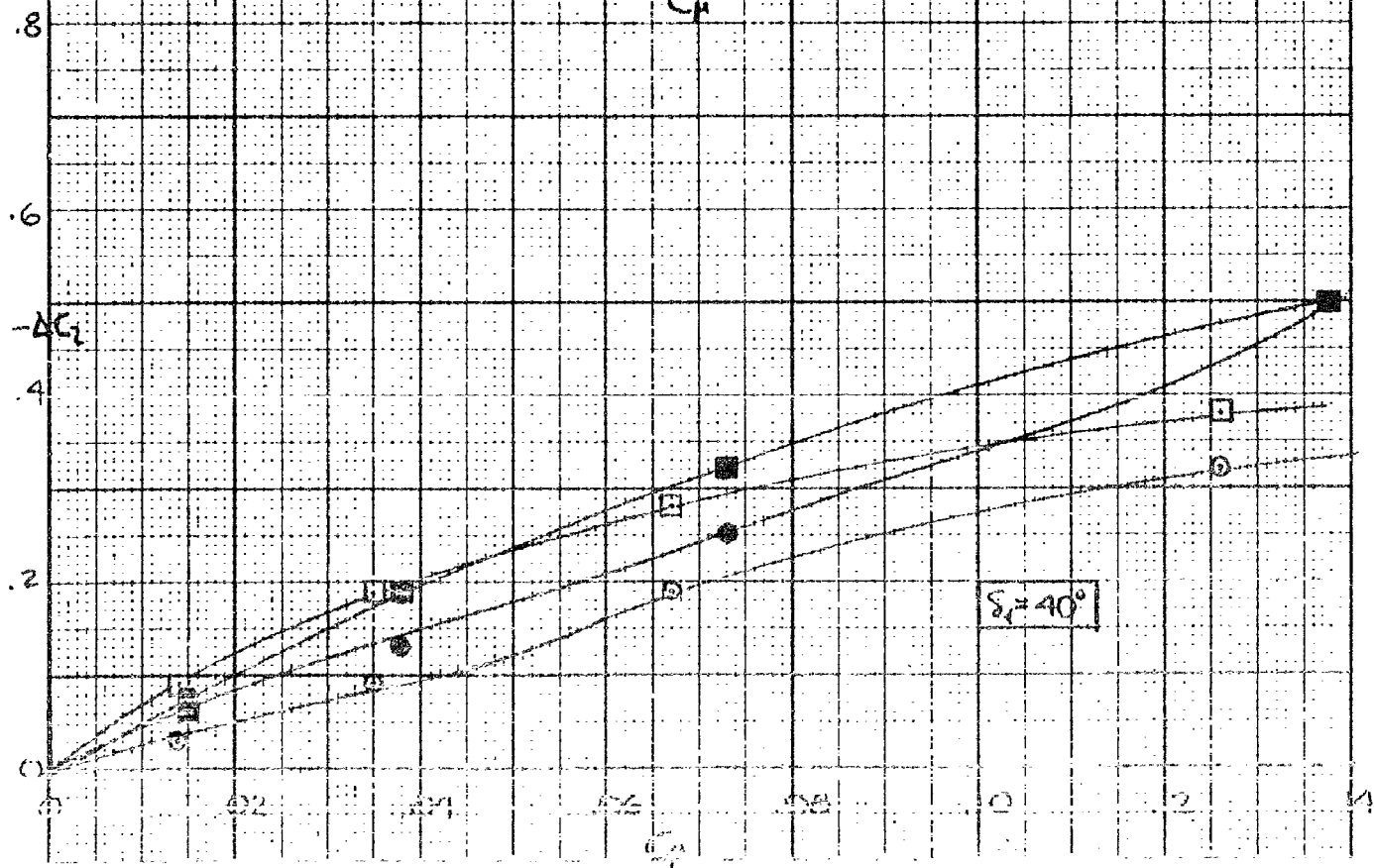
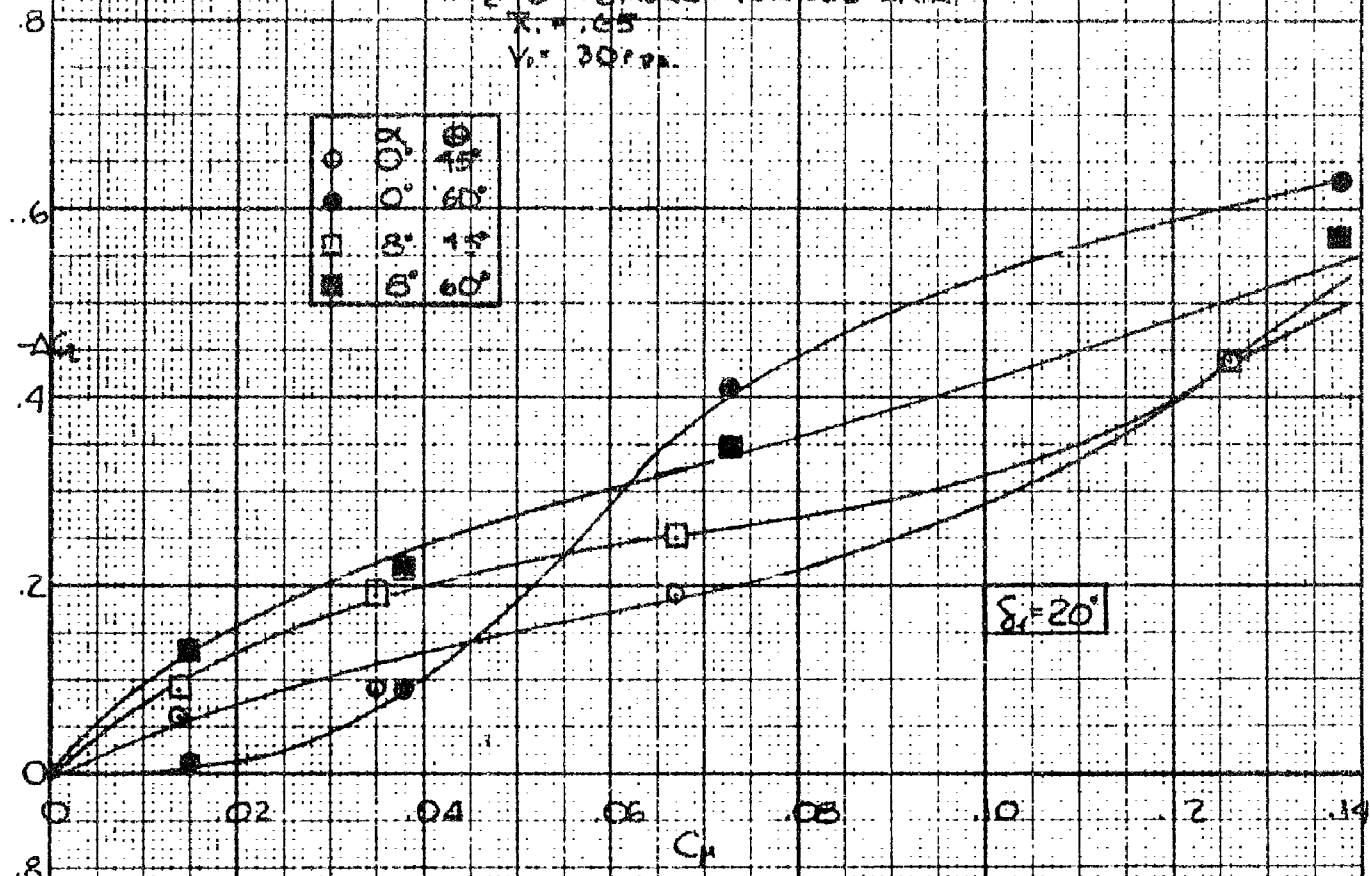
$X/c = .05$

$V_\infty = 30 \text{ ft/sec}$

○	0°	10°
●	0°	20°
□	0°	30°
■	0°	40°

EUGENE DIETZEN CO.
MADE IN U. S. A.

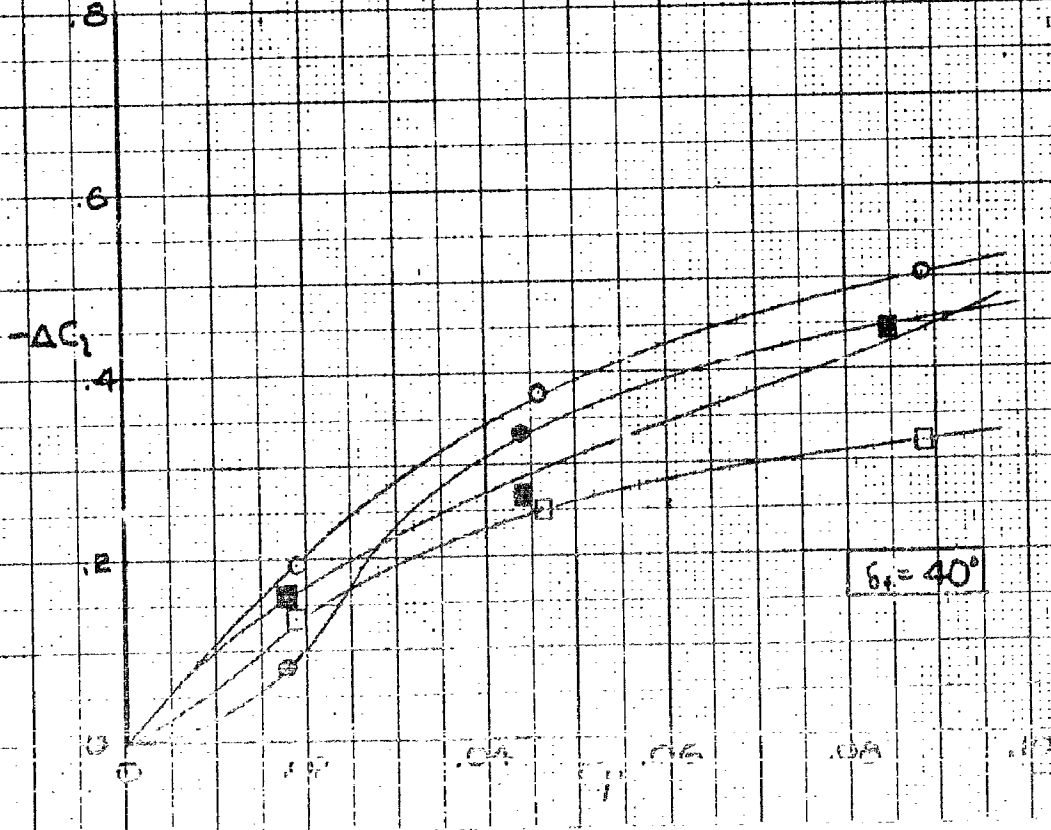
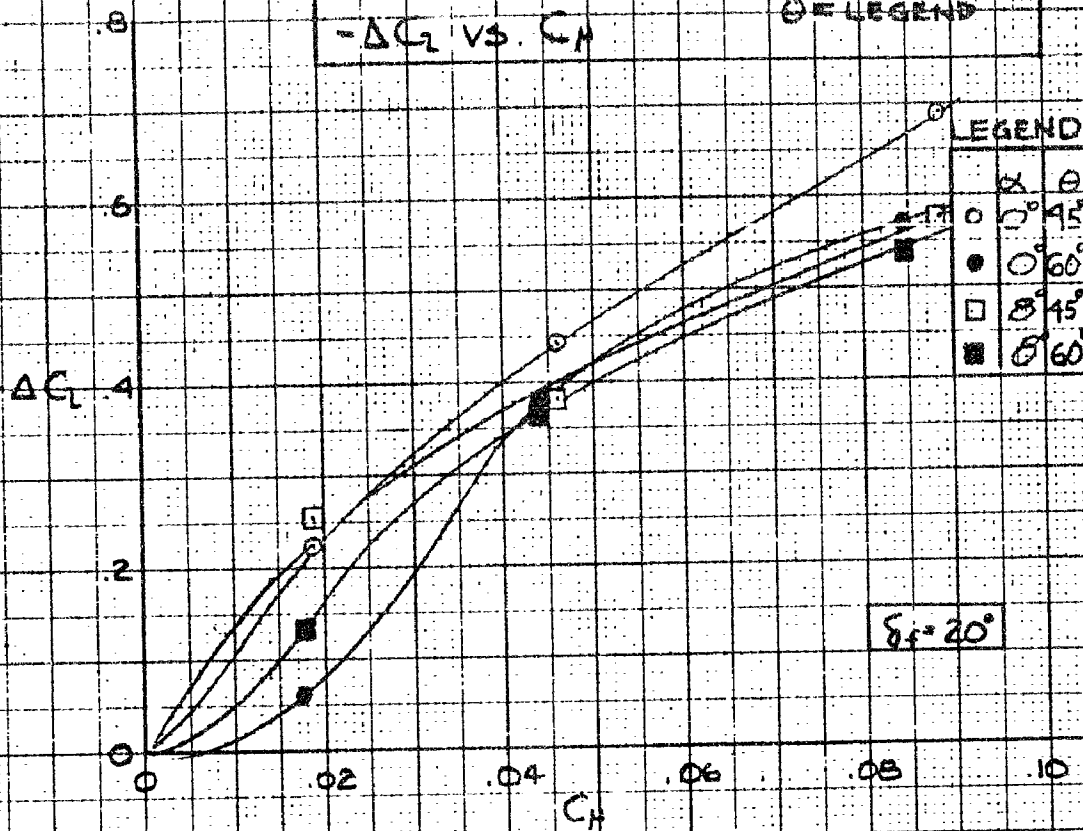
NC 340 1-20 DIETZEN GRAPH PAPER
20 X 20 PER INCH



CONFIDENTIAL

FIG. 22

NACA 23015 MODIFIED WITH
JET SPOILER
.44 C PLAIN FLAP
 $Re = 2.48 \times 10^5$
 $\delta_f = .65$
 $\theta = \text{LEGEND}$



CONFIDENTIAL

NACA 23015 WITH JET SPOILER

FLAP: 25% SLOTTED

$V_0 = 133 \text{ M.P.H.}$ $Re = 11,000,000$

EFFECT OF SEALING SLOT

PRESSURE DISTRIBUTION

$\alpha = 5^\circ$

$\alpha = 15^\circ$

$\alpha = 20^\circ$

$\alpha = 25^\circ$

$\alpha = 30^\circ$

$\alpha = 35^\circ$

$\alpha = 40^\circ$

$\alpha = 45^\circ$

$\alpha = 50^\circ$

$\alpha = 55^\circ$

$\alpha = 60^\circ$

$\alpha = 65^\circ$

$\alpha = 70^\circ$

$\alpha = 75^\circ$

$\alpha = 80^\circ$

$\alpha = 85^\circ$

$\alpha = 90^\circ$

$\alpha = 95^\circ$

$\alpha = 100^\circ$

$\alpha = 105^\circ$

$\alpha = 110^\circ$

$\alpha = 115^\circ$

$\alpha = 120^\circ$

$\alpha = 125^\circ$

$\alpha = 130^\circ$

$\alpha = 135^\circ$

$\alpha = 140^\circ$

$\alpha = 145^\circ$

$\alpha = 150^\circ$

$\alpha = 155^\circ$

$\alpha = 160^\circ$

$\alpha = 165^\circ$

$\alpha = 170^\circ$

$\alpha = 175^\circ$

$\alpha = 180^\circ$

$\alpha = 185^\circ$

$\alpha = 190^\circ$

$\alpha = 195^\circ$

$\alpha = 200^\circ$

$\alpha = 205^\circ$

$\alpha = 210^\circ$

$\alpha = 215^\circ$

$\alpha = 220^\circ$

$\alpha = 225^\circ$

$\alpha = 230^\circ$

$\alpha = 235^\circ$

$\alpha = 240^\circ$

$\alpha = 245^\circ$

$\alpha = 250^\circ$

$\alpha = 255^\circ$

$\alpha = 260^\circ$

$\alpha = 265^\circ$

$\alpha = 270^\circ$

$\alpha = 275^\circ$

$\alpha = 280^\circ$

$\alpha = 285^\circ$

$\alpha = 290^\circ$

$\alpha = 295^\circ$

$\alpha = 300^\circ$

$\alpha = 305^\circ$

$\alpha = 310^\circ$

$\alpha = 315^\circ$

$\alpha = 320^\circ$

$\alpha = 325^\circ$

$\alpha = 330^\circ$

$\alpha = 335^\circ$

$\alpha = 340^\circ$

$\alpha = 345^\circ$

$\alpha = 350^\circ$

$\alpha = 355^\circ$

$\alpha = 360^\circ$

$\alpha = 365^\circ$

$\alpha = 370^\circ$

$\alpha = 375^\circ$

$\alpha = 380^\circ$

$\alpha = 385^\circ$

$\alpha = 390^\circ$

$\alpha = 395^\circ$

$\alpha = 400^\circ$

$\alpha = 405^\circ$

$\alpha = 410^\circ$

$\alpha = 415^\circ$

$\alpha = 420^\circ$

$\alpha = 425^\circ$

$\alpha = 430^\circ$

$\alpha = 435^\circ$

$\alpha = 440^\circ$

$\alpha = 445^\circ$

$\alpha = 450^\circ$

$\alpha = 455^\circ$

$\alpha = 460^\circ$

$\alpha = 465^\circ$

$\alpha = 470^\circ$

$\alpha = 475^\circ$

$\alpha = 480^\circ$

$\alpha = 485^\circ$

$\alpha = 490^\circ$

$\alpha = 495^\circ$

$\alpha = 500^\circ$

$\alpha = 505^\circ$

$\alpha = 510^\circ$

$\alpha = 515^\circ$

$\alpha = 520^\circ$

$\alpha = 525^\circ$

$\alpha = 530^\circ$

$\alpha = 535^\circ$

$\alpha = 540^\circ$

$\alpha = 545^\circ$

$\alpha = 550^\circ$

$\alpha = 555^\circ$

$\alpha = 560^\circ$

$\alpha = 565^\circ$

$\alpha = 570^\circ$

$\alpha = 575^\circ$

$\alpha = 580^\circ$

$\alpha = 585^\circ$

$\alpha = 590^\circ$

$\alpha = 595^\circ$

$\alpha = 600^\circ$

$\alpha = 605^\circ$

$\alpha = 610^\circ$

$\alpha = 615^\circ$

$\alpha = 620^\circ$

$\alpha = 625^\circ$

$\alpha = 630^\circ$

$\alpha = 635^\circ$

$\alpha = 640^\circ$

$\alpha = 645^\circ$

$\alpha = 650^\circ$

$\alpha = 655^\circ$

$\alpha = 660^\circ$

$\alpha = 665^\circ$

$\alpha = 670^\circ$

$\alpha = 675^\circ$

$\alpha = 680^\circ$

$\alpha = 685^\circ$

$\alpha = 690^\circ$

$\alpha = 695^\circ$

$\alpha = 700^\circ$

$\alpha = 705^\circ$

$\alpha = 710^\circ$

$\alpha = 715^\circ$

$\alpha = 720^\circ$

$\alpha = 725^\circ$

$\alpha = 730^\circ$

$\alpha = 735^\circ$

$\alpha = 740^\circ$

$\alpha = 745^\circ$

$\alpha = 750^\circ$

$\alpha = 755^\circ$

$\alpha = 760^\circ$

$\alpha = 765^\circ$

$\alpha = 770^\circ$

$\alpha = 775^\circ$

$\alpha = 780^\circ$

$\alpha = 785^\circ$

$\alpha = 790^\circ$

$\alpha = 795^\circ$

$\alpha = 800^\circ$

$\alpha = 805^\circ$

$\alpha = 810^\circ$

$\alpha = 815^\circ$

$\alpha = 820^\circ$

$\alpha = 825^\circ$

$\alpha = 830^\circ$

$\alpha = 835^\circ$

$\alpha = 840^\circ$

$\alpha = 845^\circ$

$\alpha = 850^\circ$

$\alpha = 855^\circ$

$\alpha = 860^\circ$

$\alpha = 865^\circ$

$\alpha = 870^\circ$

$\alpha = 875^\circ$

$\alpha = 880^\circ$

$\alpha = 885^\circ$

$\alpha = 890^\circ$

$\alpha = 895^\circ$

$\alpha = 900^\circ$

$\alpha = 905^\circ$

$\alpha = 910^\circ$

$\alpha = 915^\circ$

$\alpha = 920^\circ$

$\alpha = 925^\circ$

$\alpha = 930^\circ$

$\alpha = 935^\circ$

$\alpha = 940^\circ$

$\alpha = 945^\circ$

$\alpha = 950^\circ$

$\alpha = 955^\circ$

$\alpha = 960^\circ$

$\alpha = 965^\circ$

$\alpha = 970^\circ$

$\alpha = 975^\circ$

$\alpha = 980^\circ$

$\alpha = 985^\circ$

$\alpha = 990^\circ$

$\alpha = 995^\circ$

$\alpha = 1000^\circ$

$\alpha = 1005^\circ$

$\alpha = 1010^\circ$

$\alpha = 1015^\circ$

$\alpha = 1020^\circ$

$\alpha = 1025^\circ$

$\alpha = 1030^\circ$

$\alpha = 1035^\circ$

$\alpha = 1040^\circ$

$\alpha = 1045^\circ$

$\alpha = 1050^\circ$

$\alpha = 1055^\circ$

$\alpha = 1060^\circ$

$\alpha = 1065^\circ$

$\alpha = 1070^\circ$

$\alpha = 1075^\circ$

$\alpha = 1080^\circ$

$\alpha = 1085^\circ$

$\alpha = 1090^\circ$

$\alpha = 1095^\circ$

$\alpha = 1100^\circ$

$\alpha = 1105^\circ$

$\alpha = 1110^\circ$

$\alpha = 1115^\circ$

$\alpha = 1120^\circ$

$\alpha = 1125^\circ$

$\alpha = 1130^\circ$

$\alpha = 1135^\circ$

$\alpha = 1140^\circ$

$\alpha = 1145^\circ$

$\alpha = 1150^\circ$

$\alpha = 1155^\circ$

$\alpha = 1160^\circ$

$\alpha = 1165^\circ$

$\alpha = 1170^\circ$

$\alpha = 1175^\circ$

$\alpha = 1180^\circ$

$\alpha = 1185^\circ$

$\alpha = 1190^\circ$

$\alpha = 1195^\circ$

$\alpha = 1200^\circ$

$\alpha = 1205^\circ$

$\alpha = 1210^\circ$

$\alpha = 1215^\circ$

$\alpha = 1220^\circ$

$\alpha = 1225^\circ$

<

CONFIDENTIAL

FIG. 24

EFFECT OF δ_f AT HIGH BLOWING

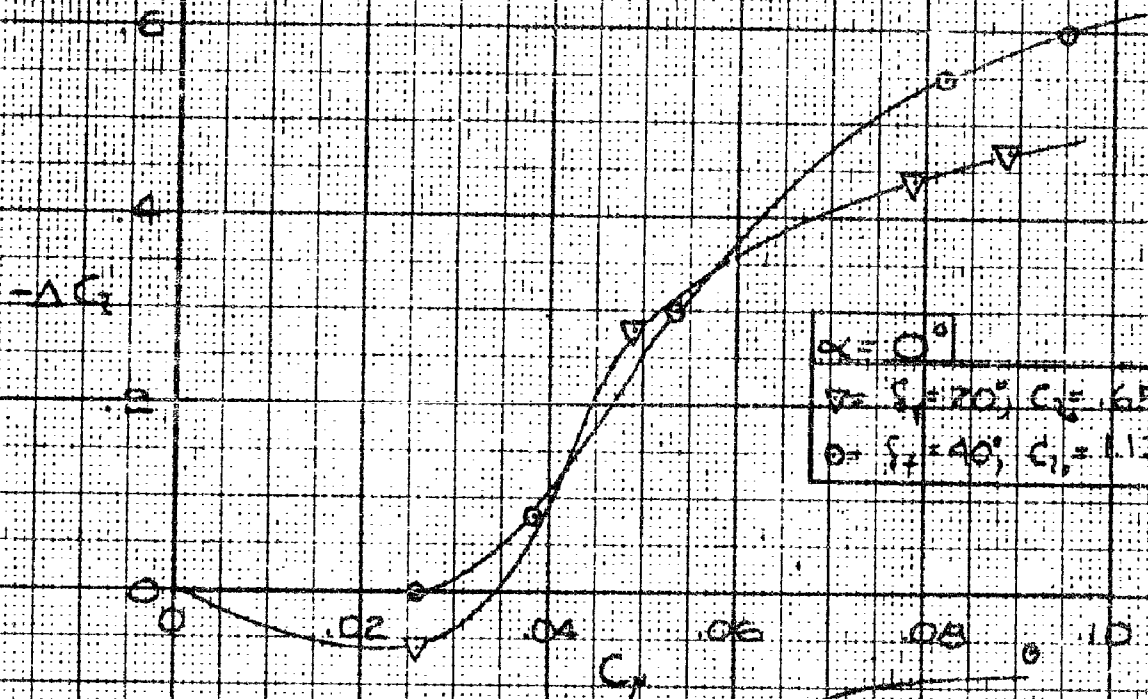
$-\Delta C_f$ vs. C_f

$Re = 5.4 \times 10^4$

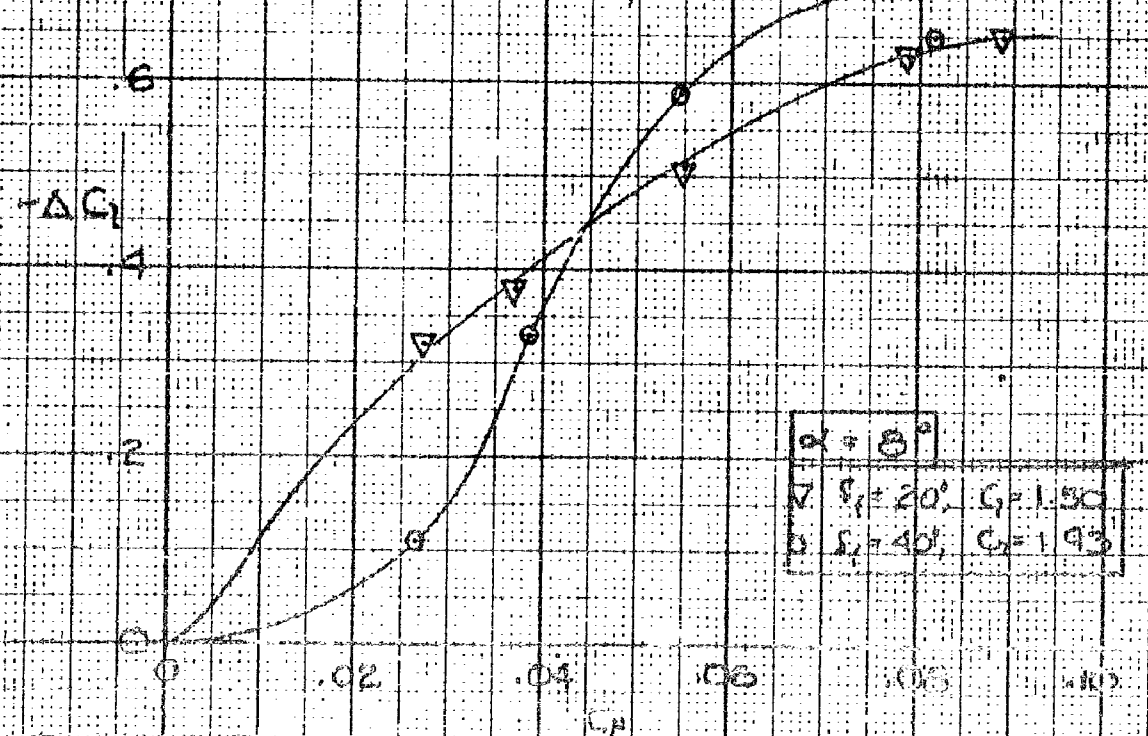
NACA 23015

25% SLOTTED FLAP

Pressure Distribution Data



$\alpha = 0^\circ$
 $\delta_f = 20^\circ, C_f = 0.65$
 $\delta_f = 40^\circ, C_f = 1.13$



$\alpha = 8^\circ$
 $\delta_f = 20^\circ, C_f = 1.50$
 $\delta_f = 40^\circ, C_f = 1.93$

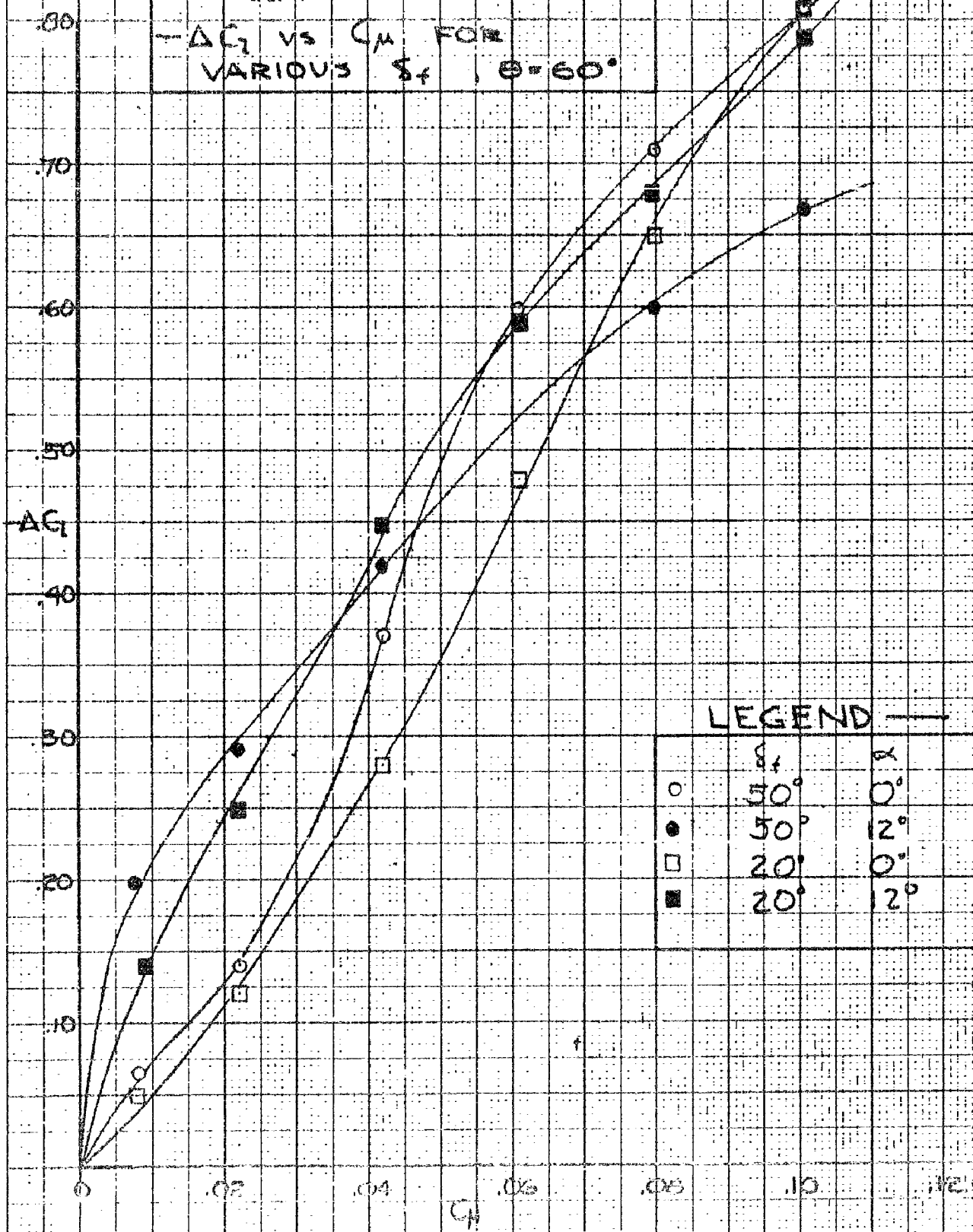
EUGENE DIETZGEN CO.
MADE IN U. S. A.

NO. 340 1:20 DIETZGEN GRAPH PAPER
20 X 20 PER INCH

CONFIDENTIAL

FIG. 25

NACA 23015 MODIFIED WITH
JET SPOILER
 $Re = 2.5 \times 10^6$
DOUBLE SLOTTED FLAP
 $-\Delta C_L$ vs C_M FOR
VARIOUS δ_f $\alpha = 60^\circ$



LEGEND

	δ_f	α	C_L
○	50°	0°	1.28
●	50°	12°	2.16
□	20°	0°	.49
■	20°	12°	1.51

10 X 10 TO THE 1/2 INCH 259-120
NEUFEL & COSEN CO

CONFIDENTIAL

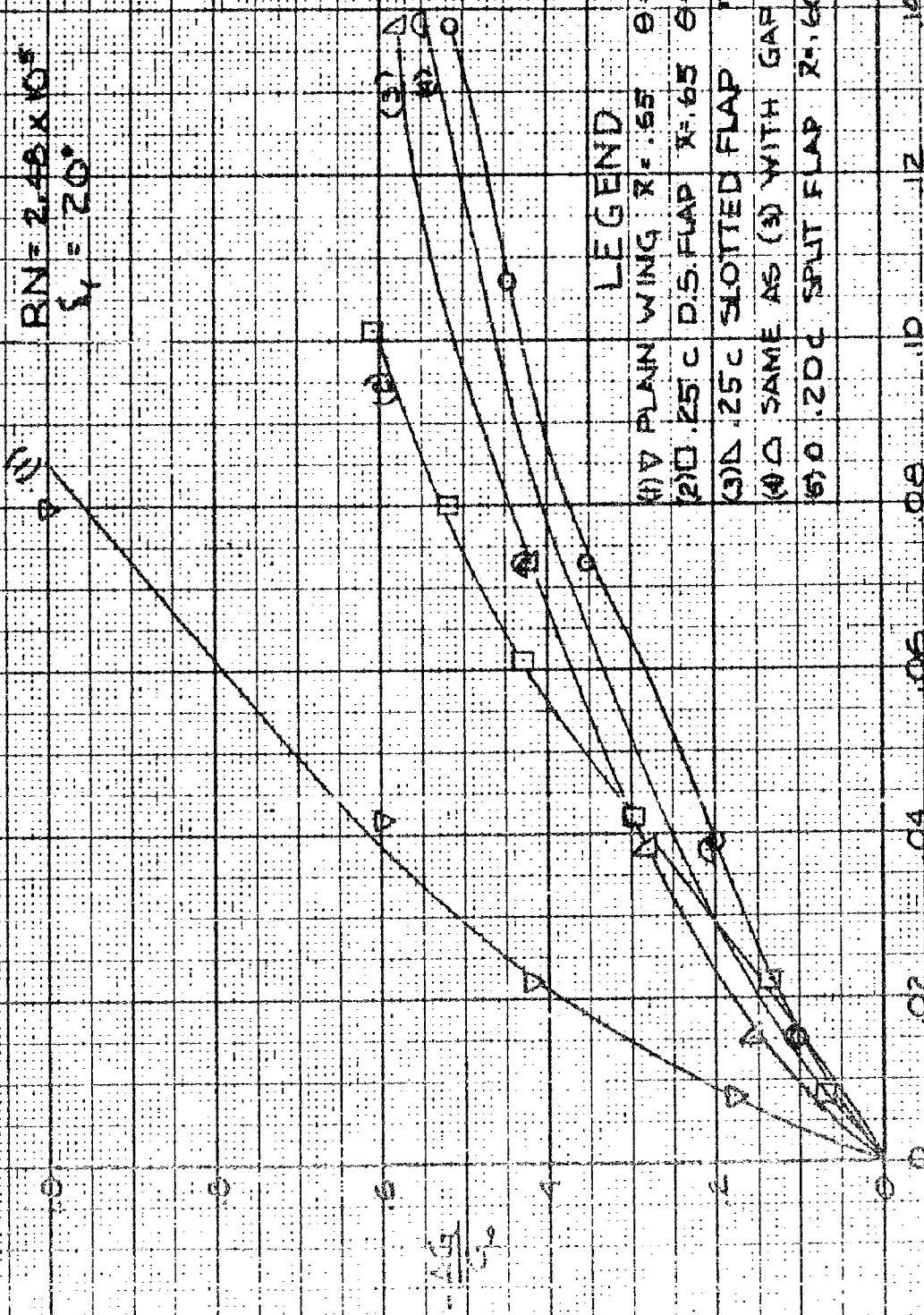
NACA 23015 MODIFIED WITH

JET SPOILER

VARIOUS FLAPS $\alpha = 8^\circ$ vs C_l

$Re = 2.48 \times 10^5$

$\alpha = 20^\circ$



LEGEND

- (1) V PLAIN WING $x = .55$ $\theta = 60^\circ$ $\alpha = 8^\circ$ $C_l = .77$
- (2) D.S. FLAP $x = .65$ $\theta = 60^\circ$ $\alpha = 8^\circ$ $C_l = .84$
- (3) SLOTTED FLAP " " " $C_l = .89$
- (4) SAME AS (3) WITH GAP SEALED
- (5) SPLIT FLAP $x = .60$ $\theta = 45^\circ$ $C_l = .82$

FIG. 26

CONFIDENTIAL

FIG. 27

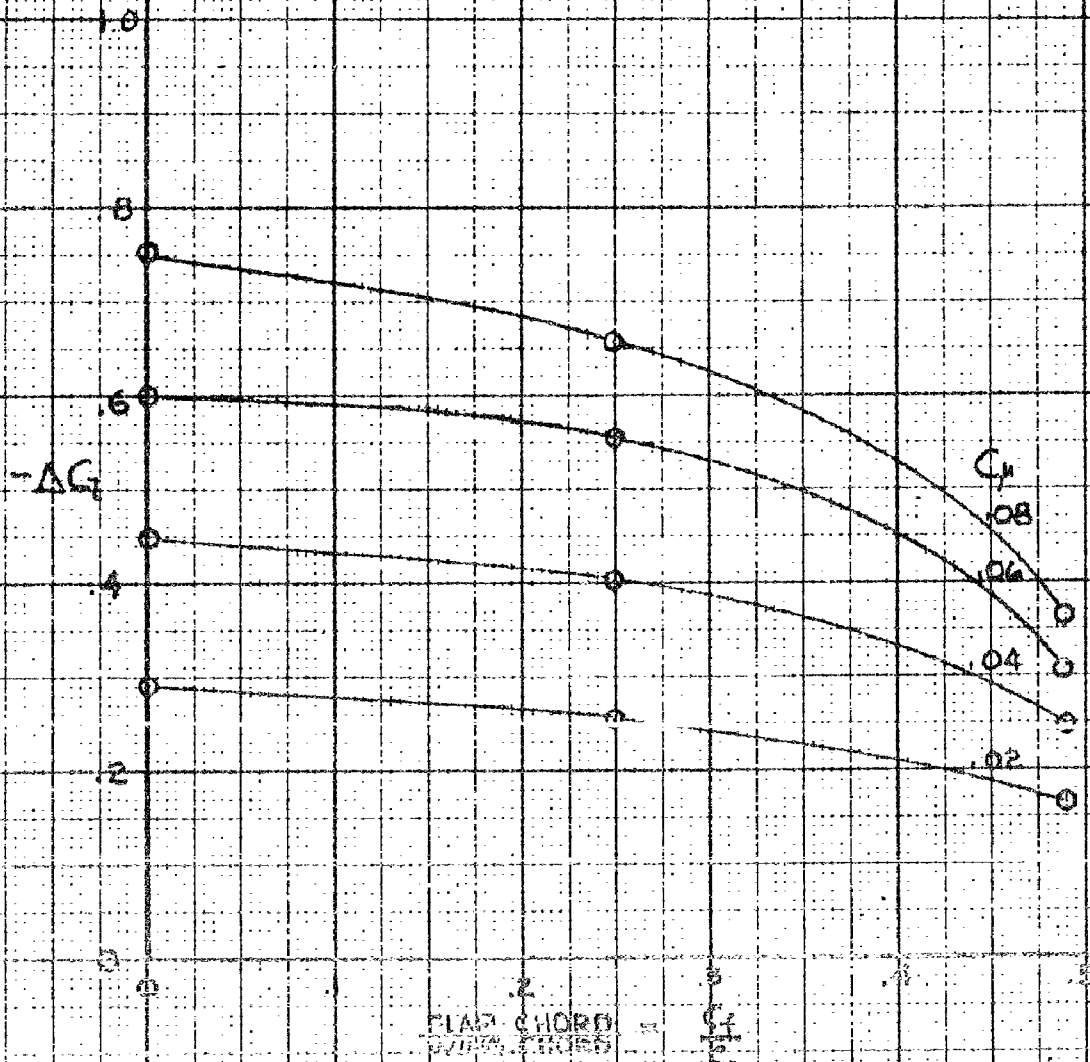
NACA 23015 MODIFIED WITH
JET SPOILER AND
SLOTTED FLAP

$Re = 2.48 \times 10^6$

$\theta = 60^\circ$

$x = .65$

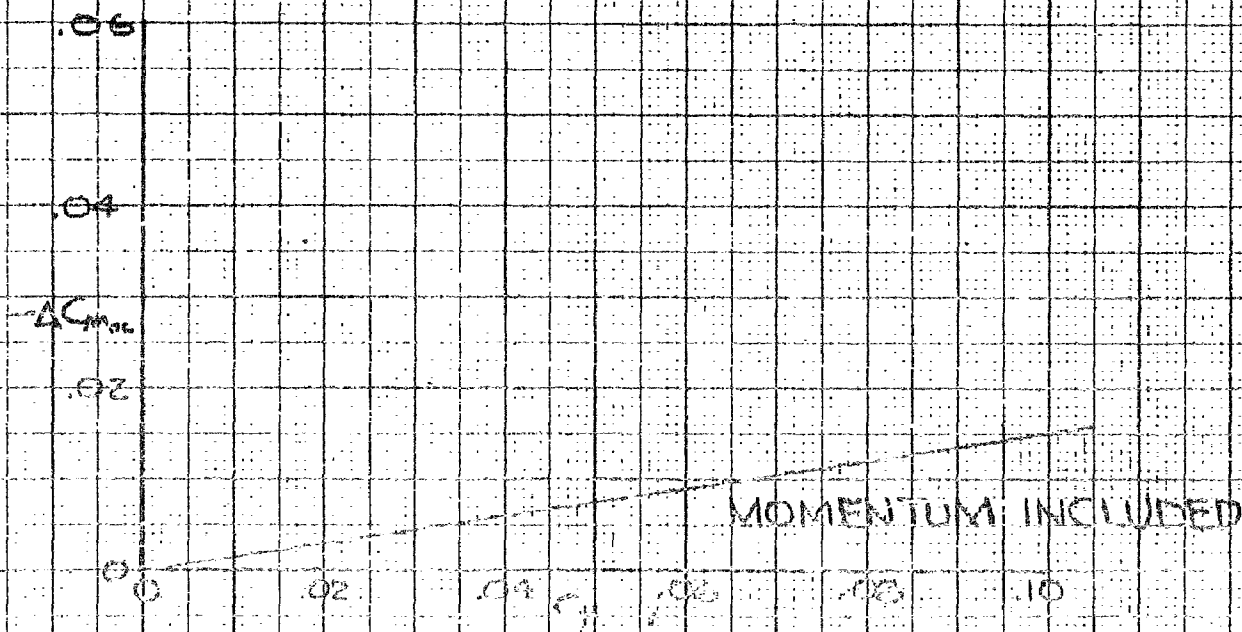
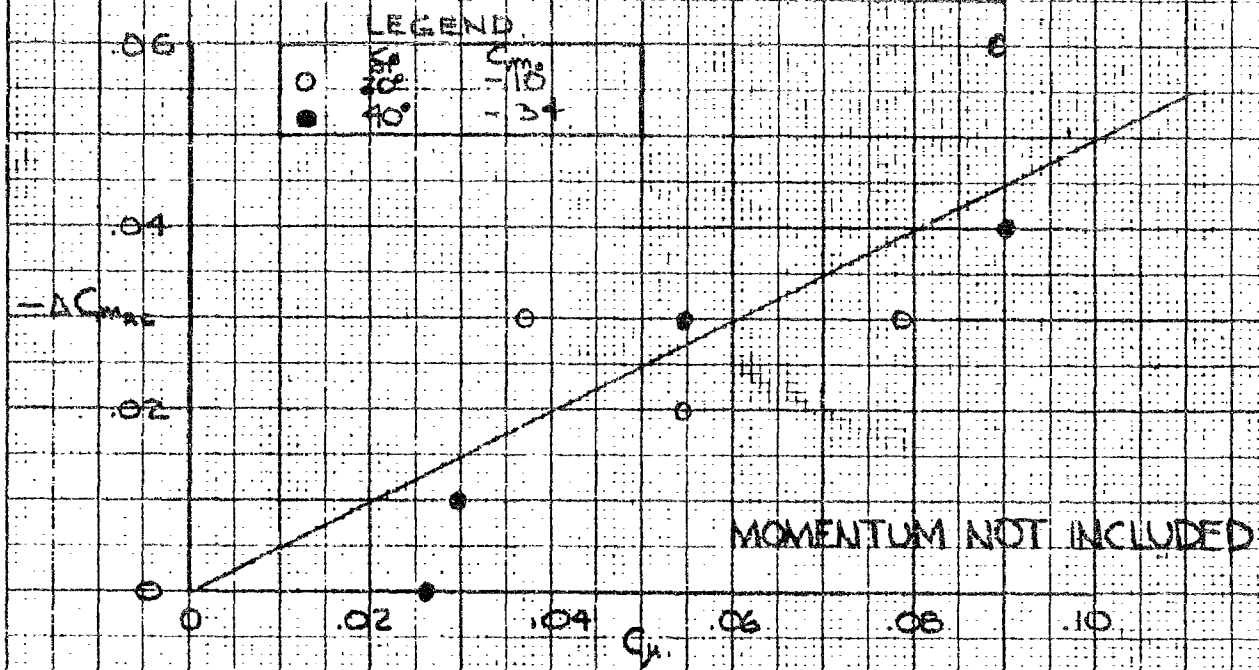
$-\Delta C_L$ vs $\frac{C_f}{C_L}$



CONFIDENTIAL

FIG. 29

NACA 23015 MODIFIED
WITH JET NOZZLES
25% SLOTTED FLAP
 $\alpha = 5^\circ$
 $\theta = 60^\circ$
 $Re = 5.4 \times 10^6$
 $-C_{m_{jet}}$ vs. C_{μ}

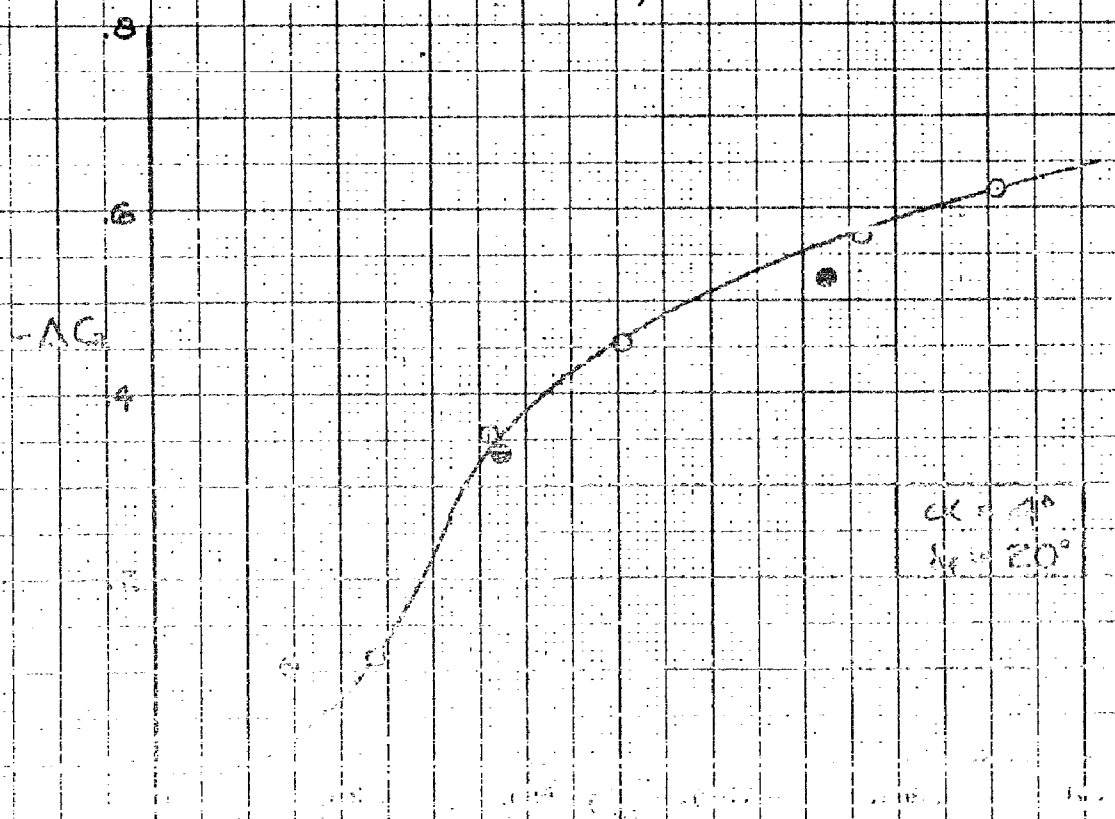
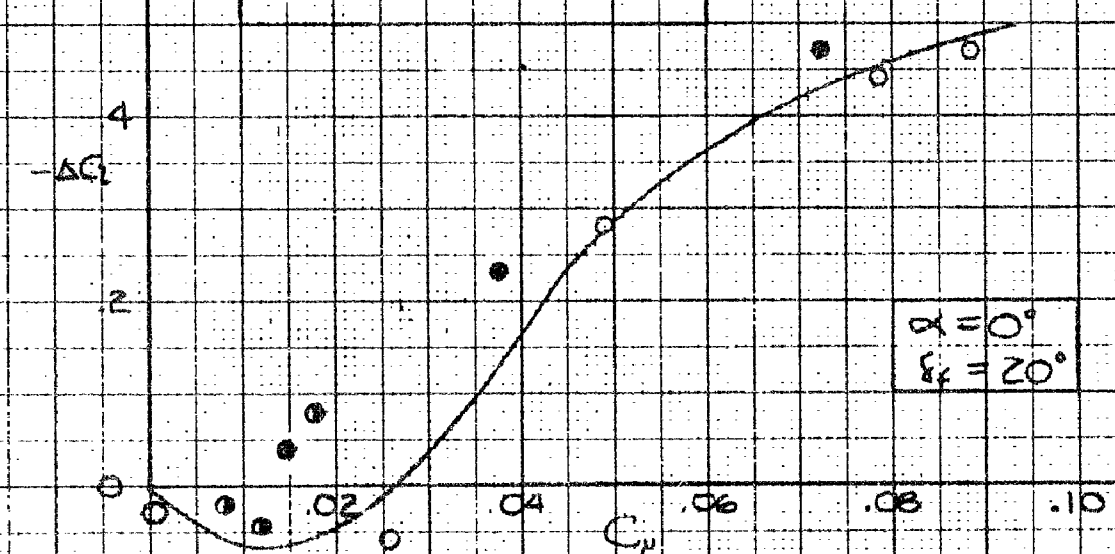


CONFIDENTIAL

PREDICTION CURVES
NACA 23015 WITH JET
SPOILER .25C GLOTTED
FLAP
 $\theta = 60^\circ$
 $\lambda = .65$ $-\Delta C_L$ VS C_{μ}

FIG. 30

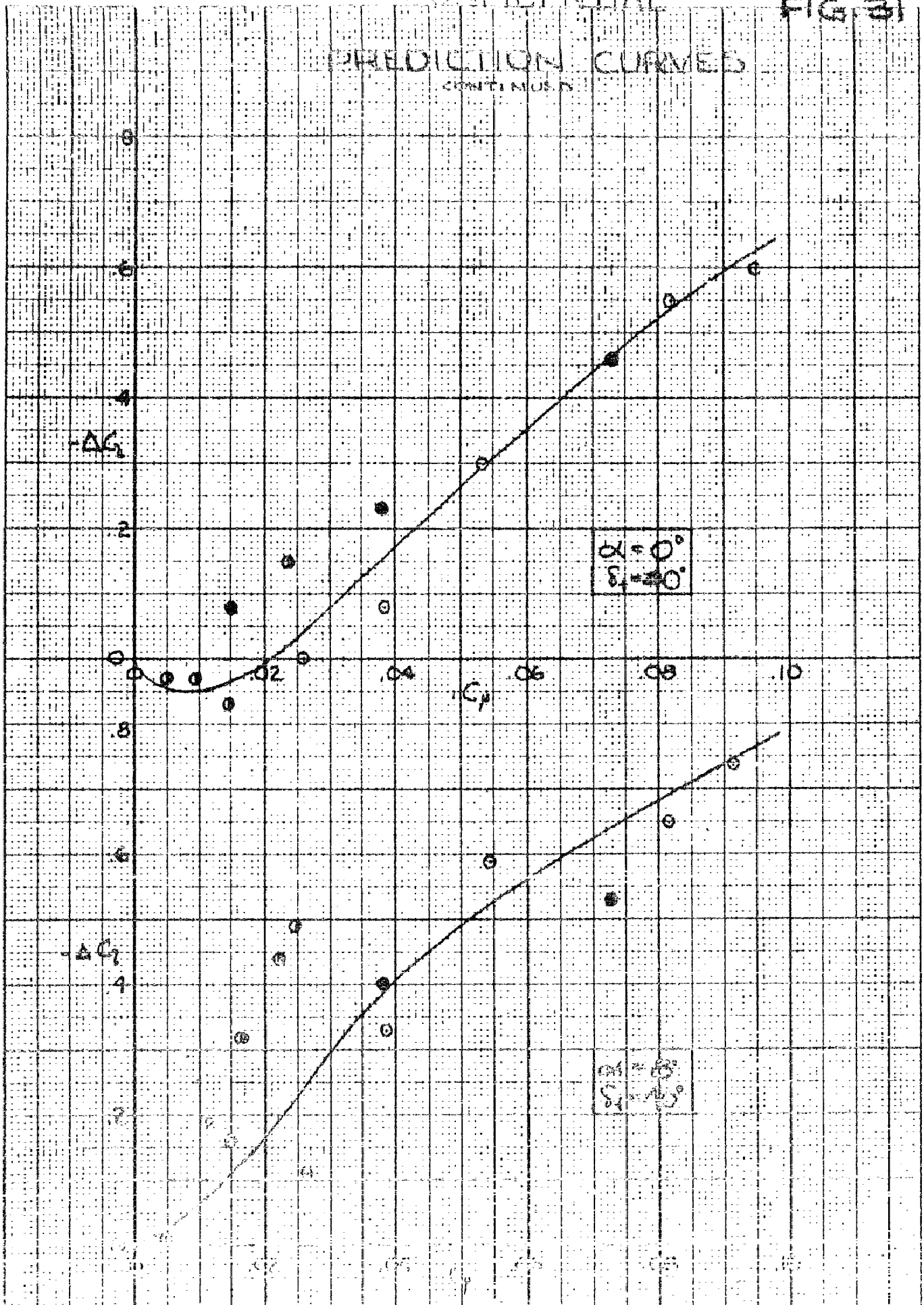
- $R_n = .34 \times 10^6$
- $= 1.08 \times 10^6$
- $= 2.48 \times 10^6$



CONFIDENTIAL

FIG 31

PREDICTION CURVES CONTINUOUS



EUGENE DIETZEN CO.
MADE IN U. S. A.

NO 340 1:20 DIETZEN GRAPH PAPER
20 X 20 PER INCH

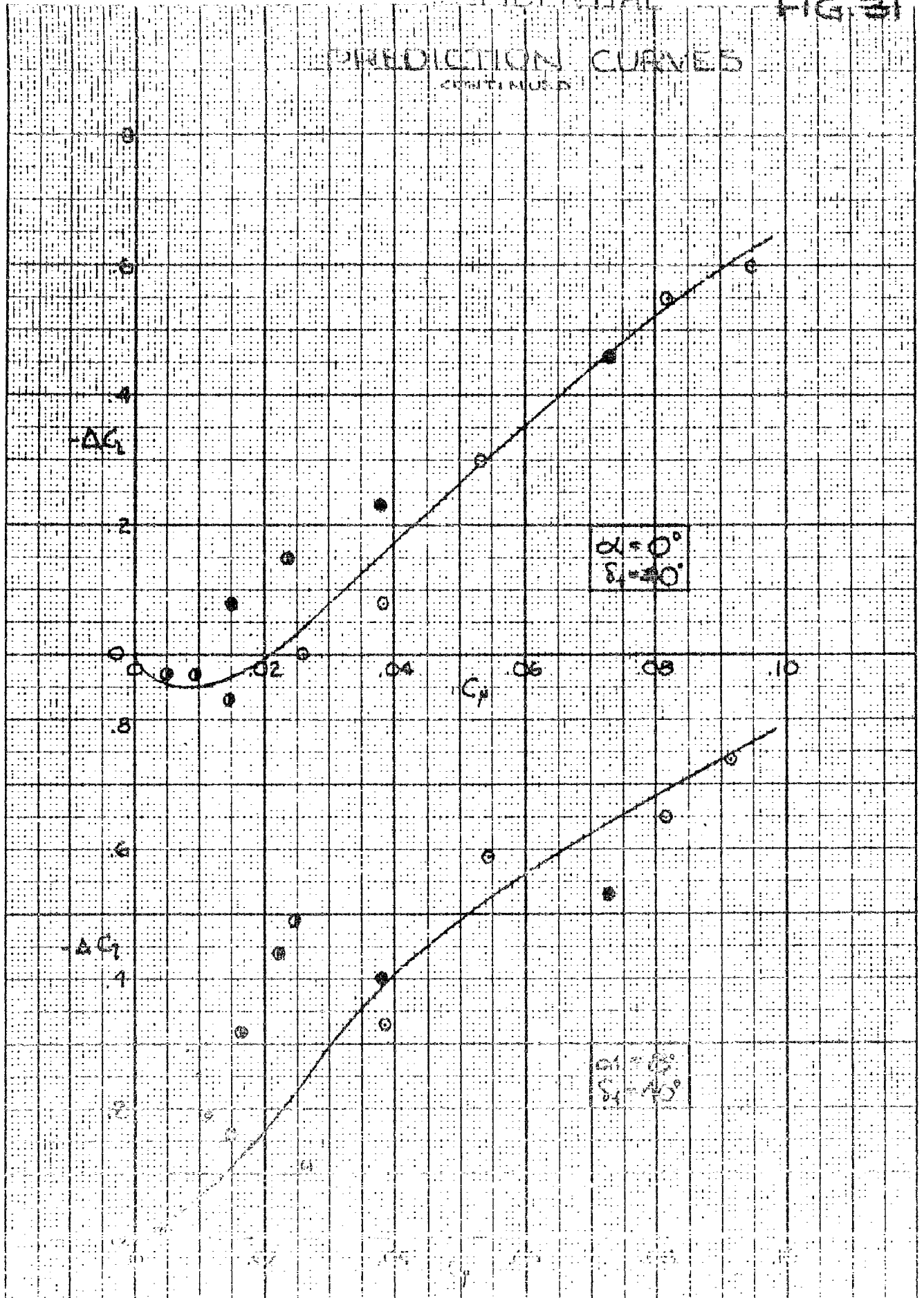
CONFIDENTIAL

FIG. 31

PREDICTION CURVES CONTINUED

EUGENE DIETZGEN CO.
MADE IN U. S. A.

NO 340 1:20 DIETZGEN GRAPH PAPER
20 X 20 PER INCH



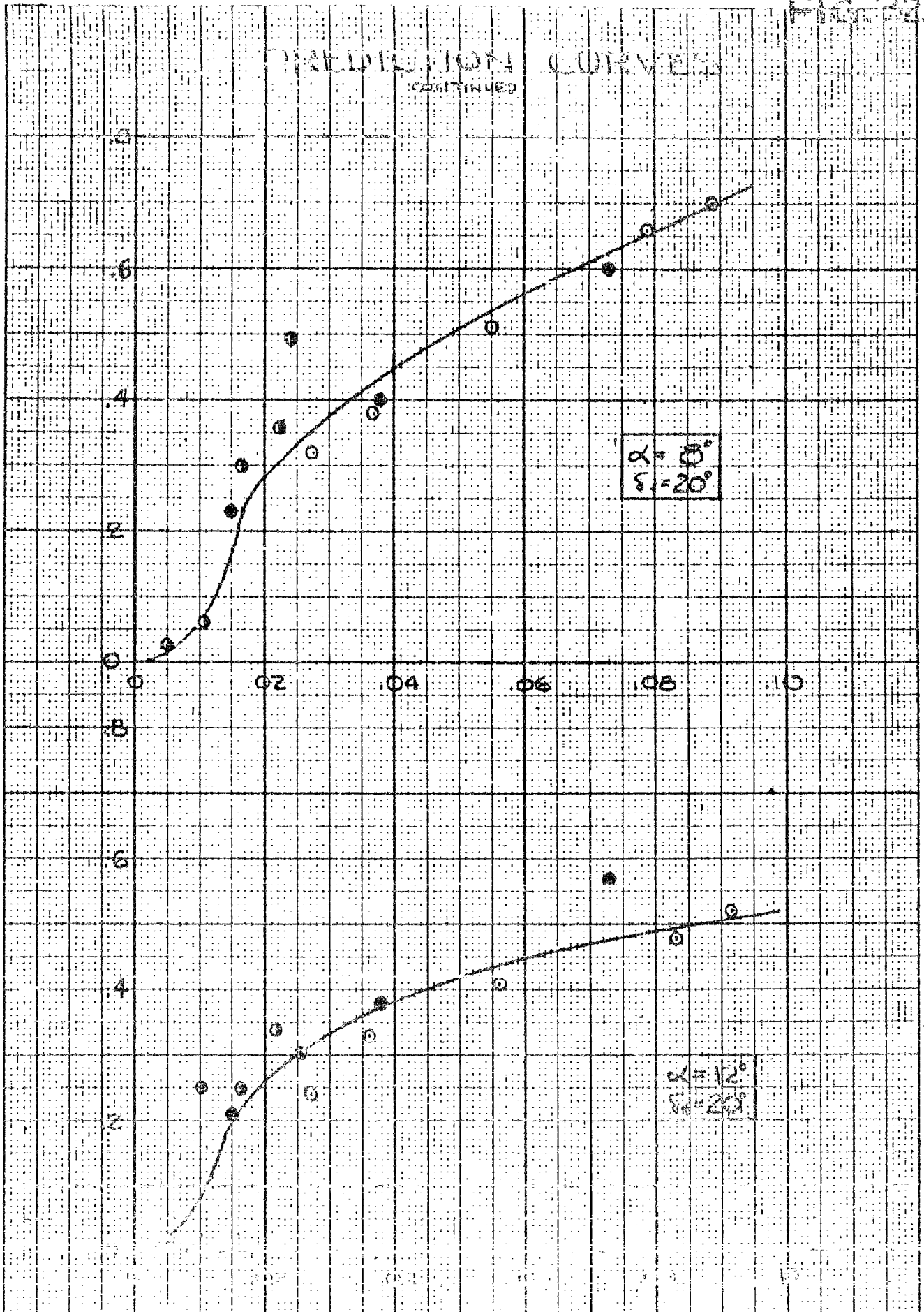
CONFIDENTIAL

FIG. 22

PREDICTION CURVES (CONTINUED)

EUGENE DIETZGEN CO.
MADE IN U. S. A.

NO 340 1:20 DIETZGEN GRAPH PAPER
20 X 20 PER INCH



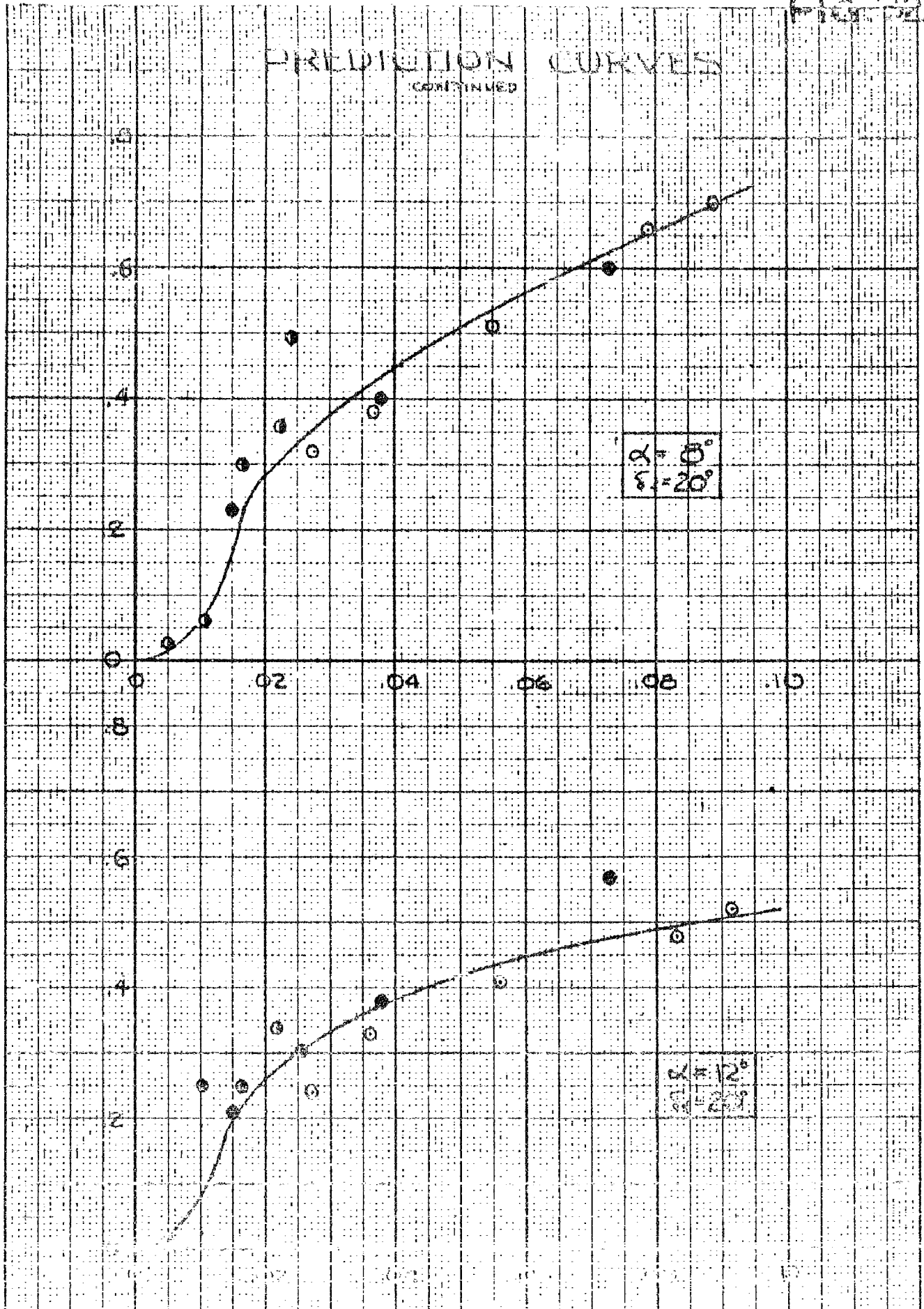
CONFIDENTIAL

Fig. 32

PREDICTION CURVES CONTINUED

EUGENE DIETZGEN CO.
MADE IN U. S. A.

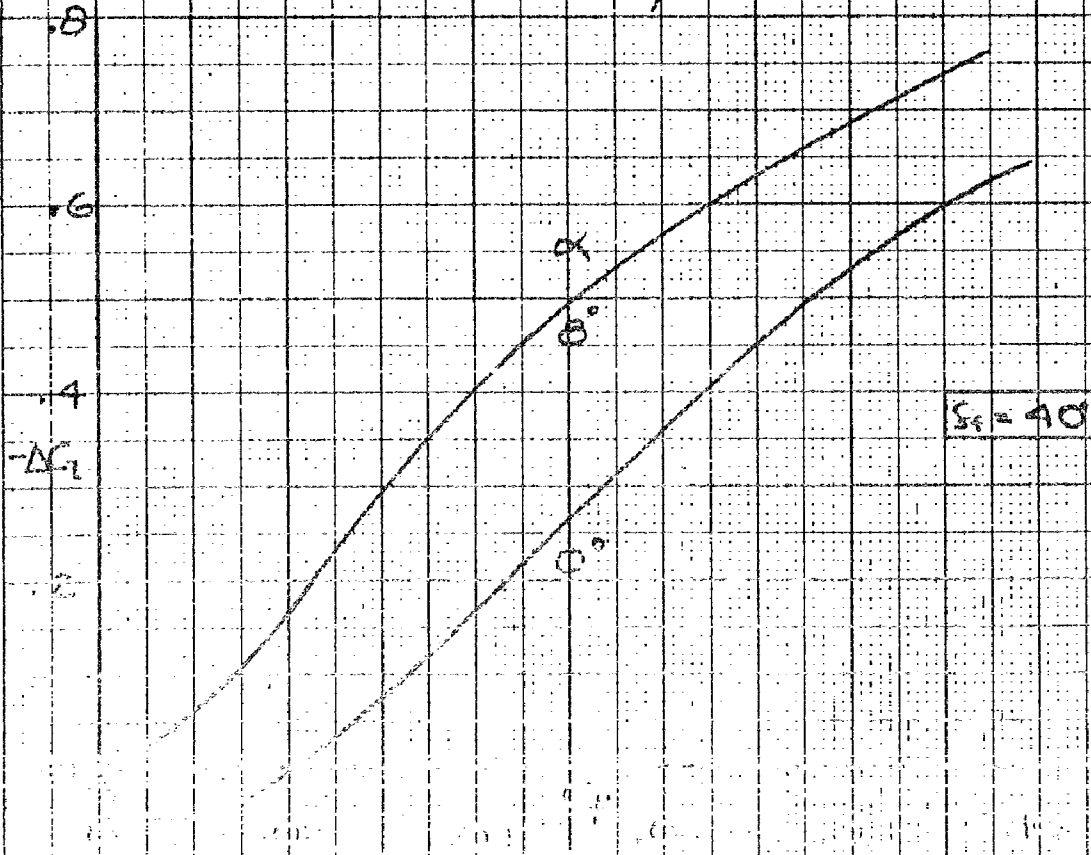
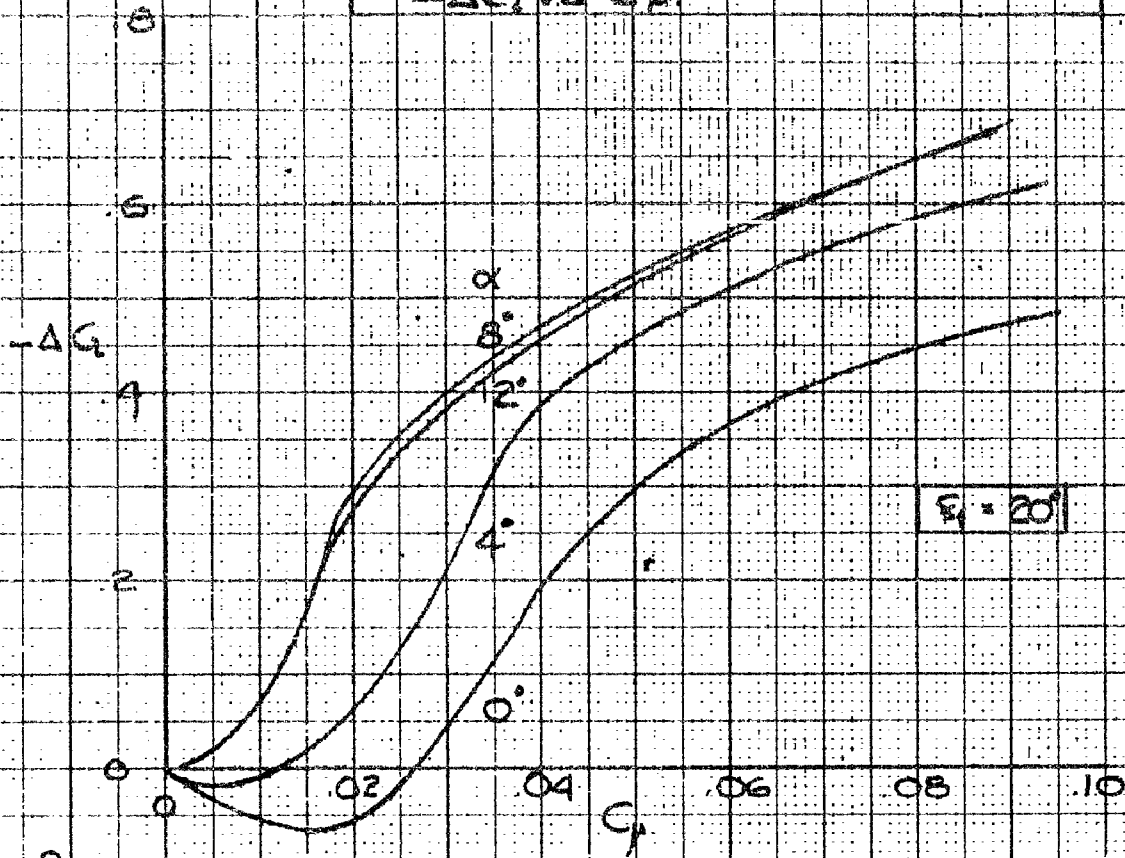
NO 340 120 DIETZGEN GRAPH PAPER
20 X 20 PER INCH



CONFIDENTIAL

NACA 23015 WITH JET
SPOILER
25% SLOTTED FLAP $\delta = 60^\circ$
PREDICTION CURVES $X = .65$
 $-\Delta C_L$ VS C_L

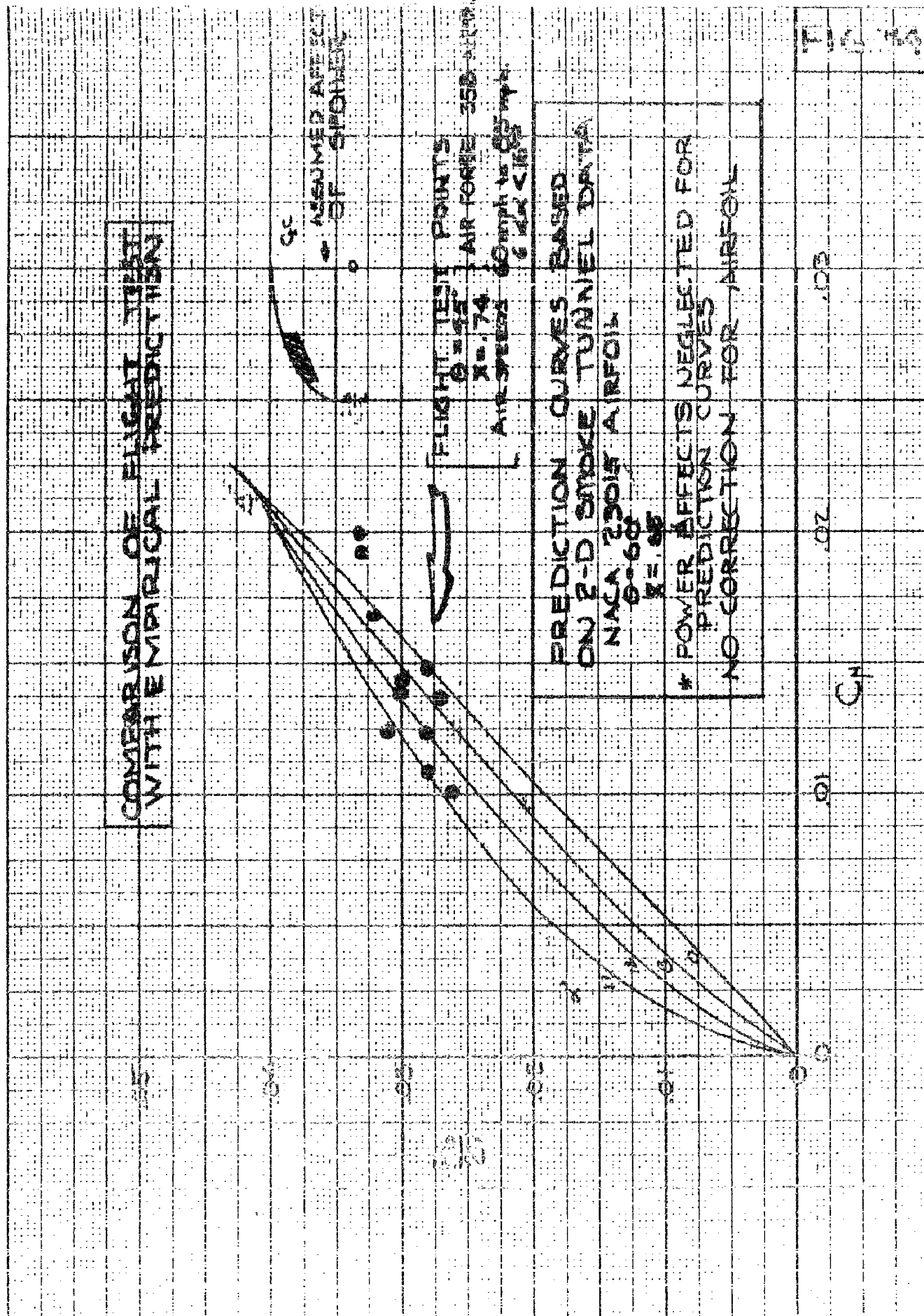
FIG 33



359-12G

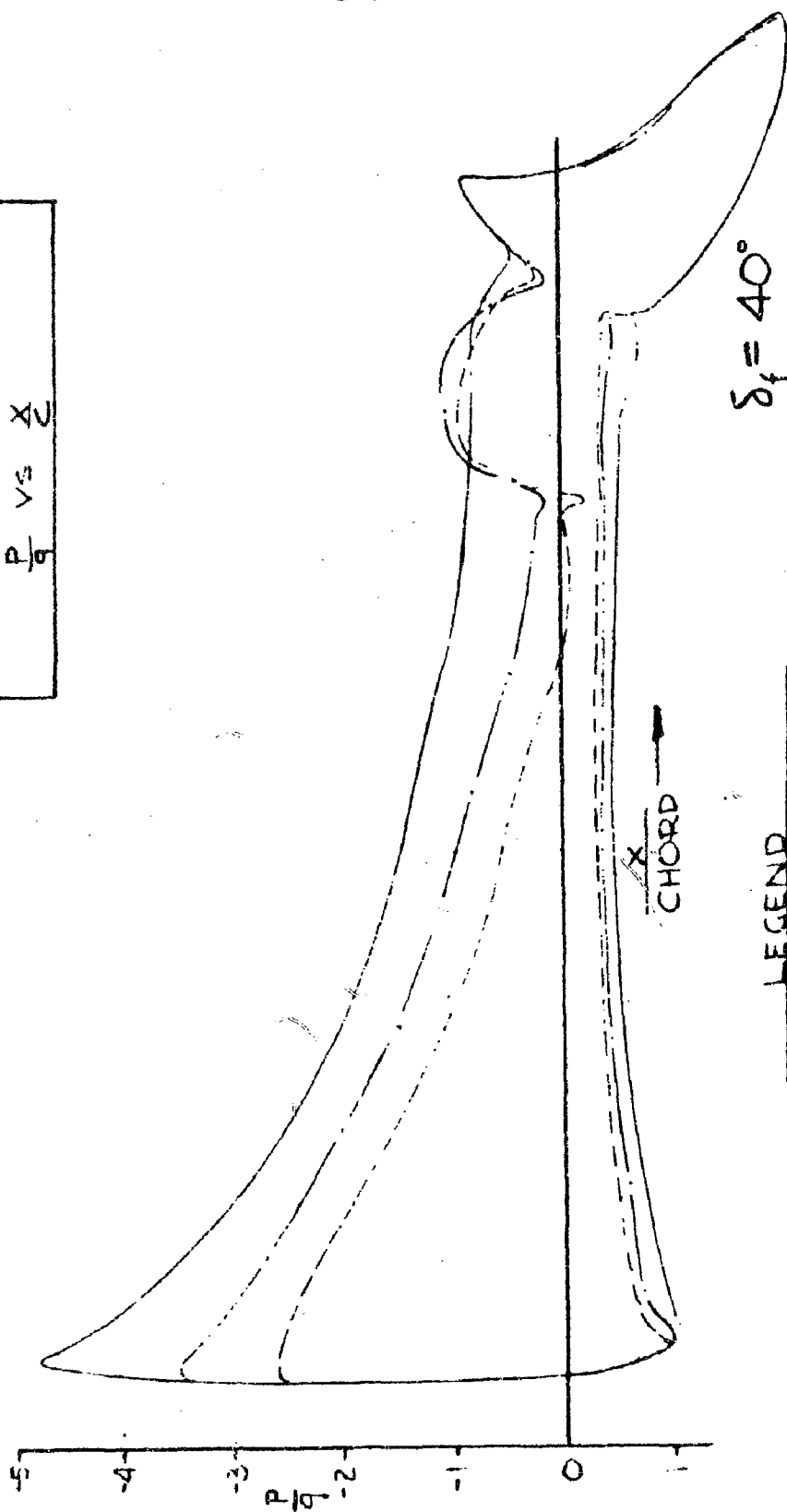
10 X 10 TO THE 1/2 INCH
KEUFFEL & ESSER CO
BALTIMORE, MD

W
Y



CONFIDENTIAL

NACA 23015 MODIFIED
WITH JET SPOILER
.25 C SLOTTED FLAP
 $\theta = 60^\circ$ $X = .65$ $\alpha = 8^\circ$
 $\frac{P}{q}$ vs $\frac{x}{c}$



LEGEND

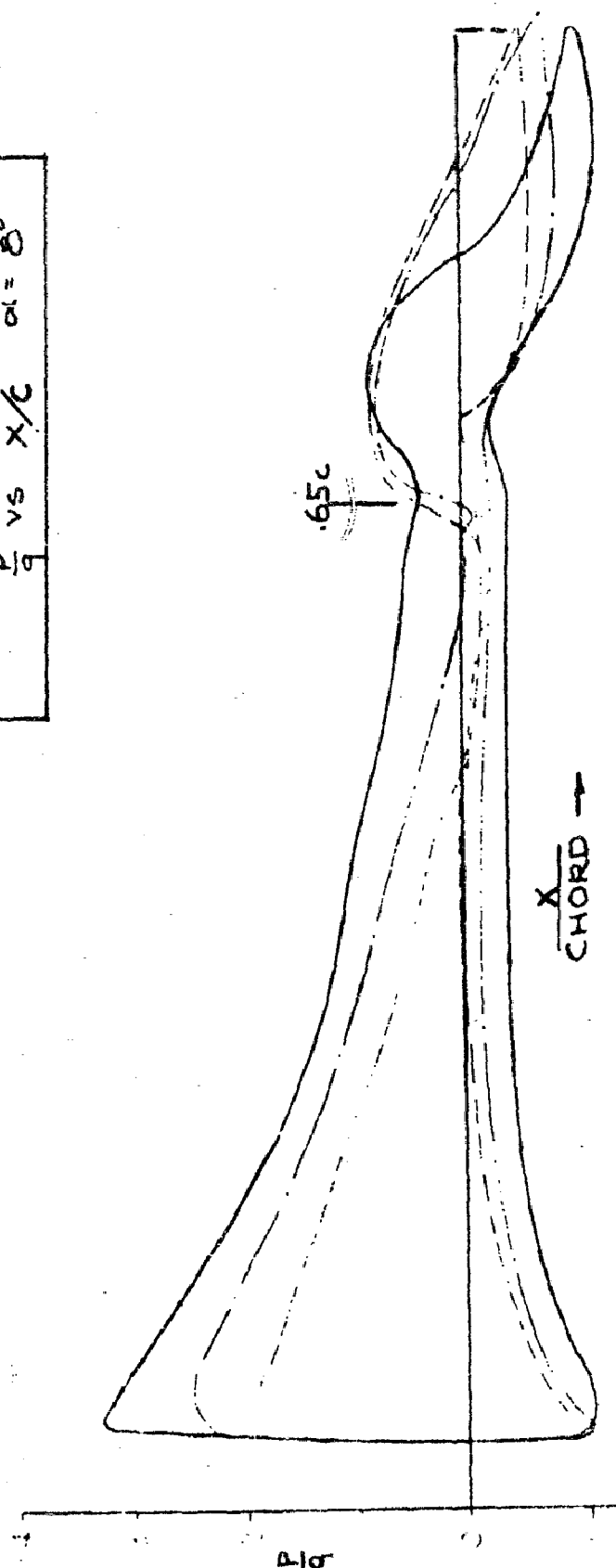
C_L	1.53
C_L	.60
C_L	.0915
C_L	.0385

CONFIDENTIAL

CONFIDENTIAL

FIG. 36

NACA 23015 MODIFIED WITH
JET SPOILER
'25c SLOTTED FLAP
 $\theta = 60^\circ$ $X = .65$ $\delta_f = 20^\circ$
 $\frac{P}{q}$ vs X/c $\alpha = 0^\circ$



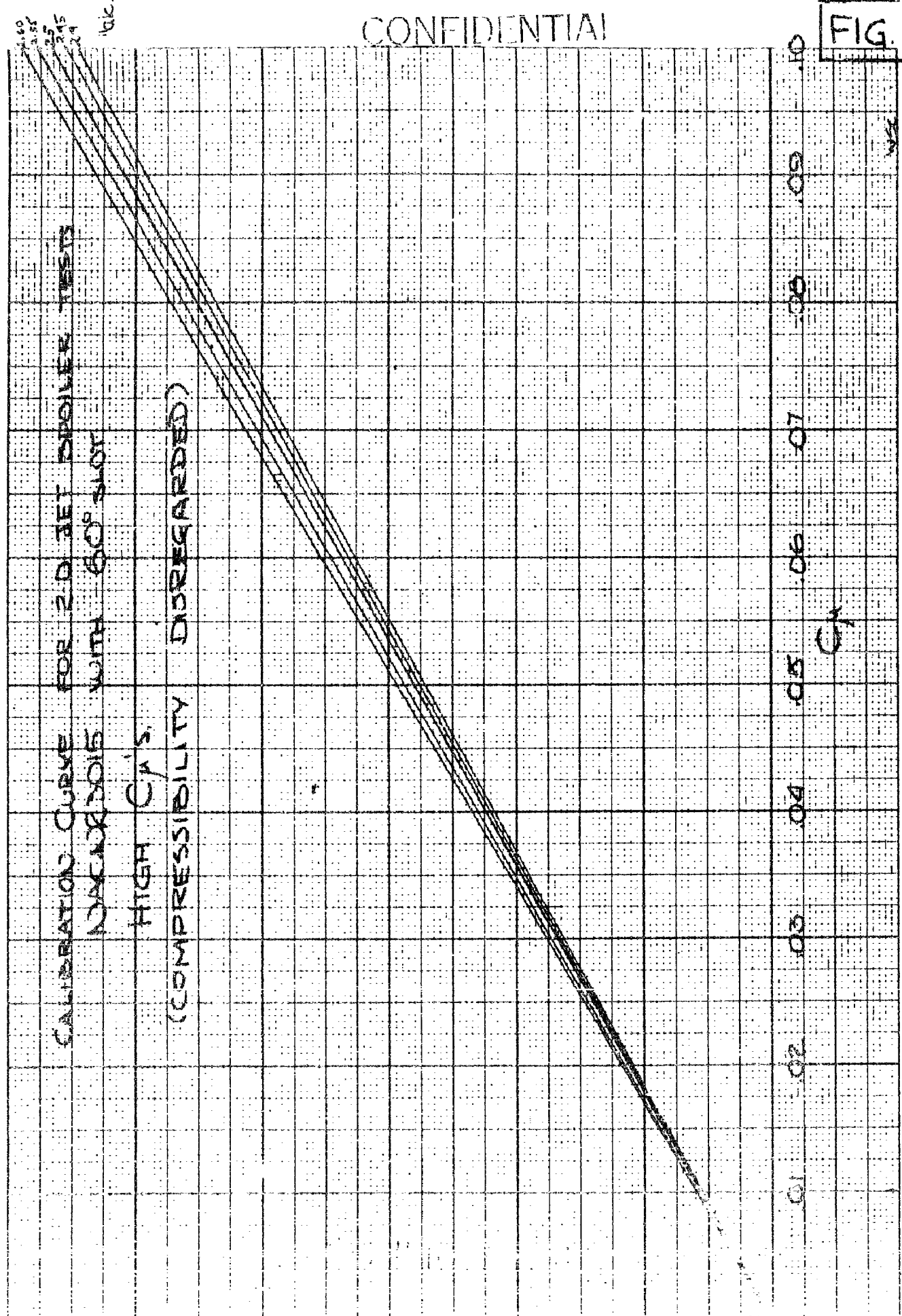
$\delta_f = 20^\circ$

LEGEND	
C_L	1.50
C_D	.037
C_{Df}	.089
C_{Df}	.86

CONFIDENTIAL

CONFIDENTIAL

FIG. 37

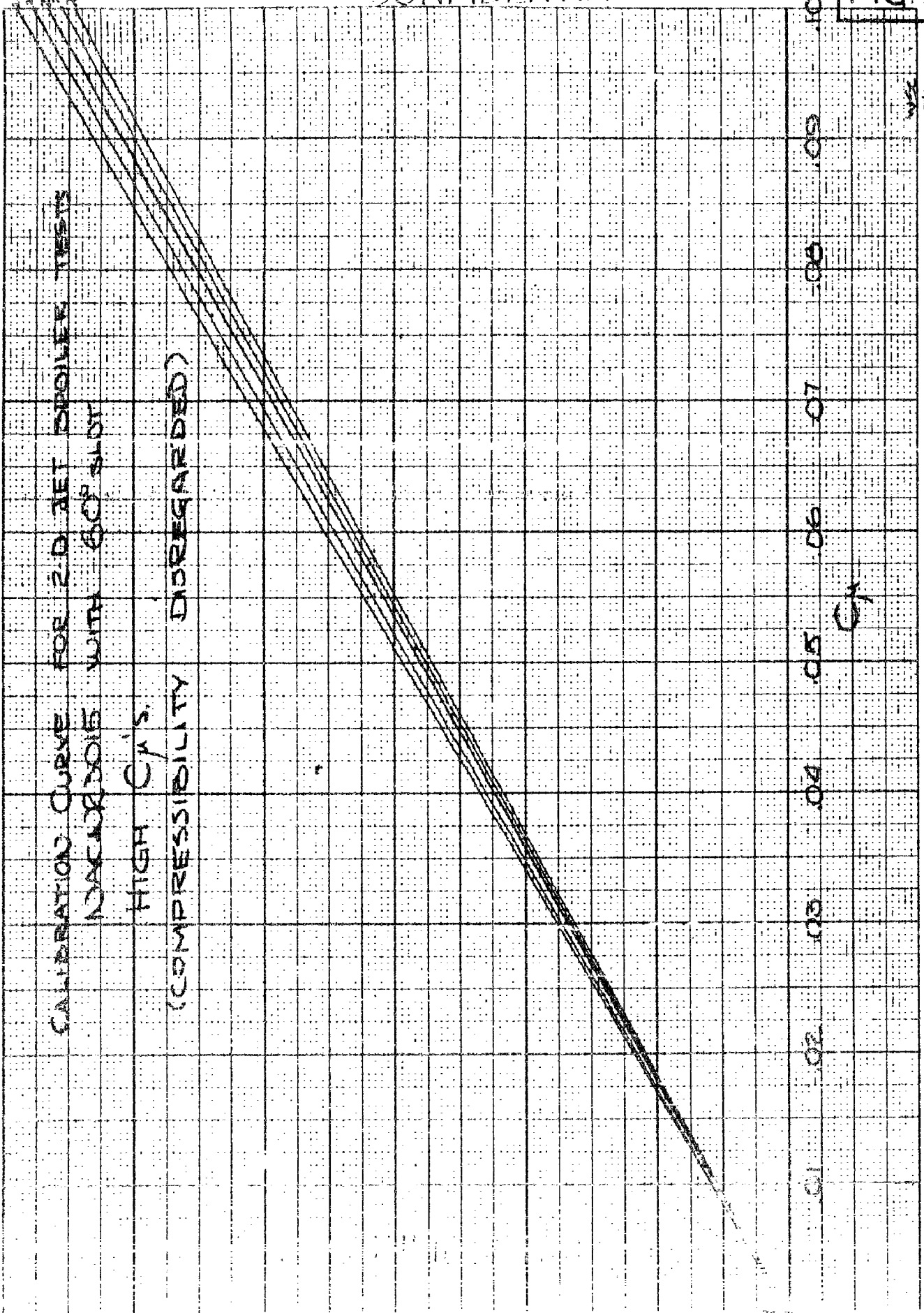


CONFIDENTIAL

FIG. 37

AP
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00

CALIBRATION CURVE FOR 2-D JET SPOILER TESTS
NACA 0015 WITH 60° SLOT
HIGH C_p 'S
(COMPRESSIBILITY DISREGARDED)



1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00

Childress, W. S., Gould, A. V. CONFIDENTIAL

Two-dimensional tests of a 23015 airfoil with a jet spoiler and various flaps. Princeton University, Department of Aeronautical Engineering. Report No. 365 - October 1956 - 62 pp. 37 fig.

1. Jet spoilers
2. Lift - reduction
3. Control - Lateral; I. Childress, W. S.; II. Gould, A. V.; III. Princeton University, Department of Aeronautical Engineering. Report No. 365.

CONFIDENTIAL

Childress, W. S., Gould, A. V. CONFIDENTIAL

Two-dimensional tests of a 23015 airfoil with a jet spoiler and various flaps. Princeton University, Department of Aeronautical Engineering. Report No. 365 - October 1956 - 62 pp. 37 fig.

1. Jet spoilers
2. Lift - reduction
3. Control - Lateral; I. Childress, W. S.; II. Gould, A. V.; III. Princeton University, Department of Aeronautical Engineering. Report No. 365.

CONFIDENTIAL

Childress, W. S., Gould, A. V. CONFIDENTIAL

Two-dimensional tests of a 23015 airfoil with a jet spoiler and various flaps. Princeton University, Department of Aeronautical Engineering. Report No. 365 - October 1956 - 62 pp. 37 fig.

1. Jet spoilers
2. Lift - reduction
3. Control - Lateral; I. Childress, W. S.; II. Gould, A. V.; III. Princeton University, Department of Aeronautical Engineering. Report No. 365.

CONFIDENTIAL

Childress, W. S., Gould, A. V. CONFIDENTIAL

Two-dimensional tests of a 23015 airfoil with a jet spoiler and various flaps. Princeton University, Department of Aeronautical Engineering. Report No. 365 - October 1956 - 62 pp. 37 fig.

1. Jet spoilers
2. Lift - reduction
3. Control - Lateral; I. Childress, W. S.; II. Gould, A. V.; III. Princeton University, Department of Aeronautical Engineering. Report No. 365.

CONFIDENTIAL

<p style="text-align: center;"><u>ABSTRACT</u> CONFIDENTIAL</p> <p>In an attempt to evaluate the effectiveness of the jet spoiler as a lateral control device, two-dimensional 23015 profiles with several familiar flaps were tested at RN from 1 to $.25 \times 10^6$. The effects of all of the major variables on the lift reductions due to jet spoiling are considered. The major problems associated with the analytical treatment of spoiling are presented and the possibility of practical application of the device is considered.</p> <p>The data represents the results of smoke tunnel studies, pressure distribution studies, and flight tests.</p> <p style="text-align: center;">CONFIDENTIAL</p>	<p style="text-align: center;"><u>ABSTRACT</u> CONFIDENTIAL</p> <p>In an attempt to evaluate the effectiveness of the jet spoiler as a lateral control device, two-dimensional 23015 profiles with several familiar flaps were tested at RN from 1 to $.25 \times 10^6$. The effects of all of the major variables on the lift reductions due to jet spoiling are considered. The major problems associated with the analytical treatment of spoiling are presented and the possibility of practical application of the device is considered.</p> <p>The data represents the results of smoke tunnel studies, pressure distribution studies, and flight tests.</p> <p style="text-align: center;">CONFIDENTIAL</p>
<p style="text-align: center;"><u>ABSTRACT</u> CONFIDENTIAL</p> <p>In an attempt to evaluate the effectiveness of the jet spoiler as a lateral control device, two-dimensional 23015 profiles with several familiar flaps were tested at RN from 1 to $.25 \times 10^6$. The effects of all of the major variables on the lift reductions due to jet spoiling are considered. The major problems associated with the analytical treatment of spoiling are presented and the possibility of practical application of the device is considered.</p> <p>The data represents the results of smoke tunnel studies, pressure distribution studies, and flight tests.</p> <p style="text-align: center;">CONFIDENTIAL</p>	<p style="text-align: center;"><u>ABSTRACT</u> CONFIDENTIAL</p> <p>In an attempt to evaluate the effectiveness of the jet spoiler as a lateral control device, two-dimensional 23015 profiles with several familiar flaps were tested at RN from 1 to $.25 \times 10^6$. The effects of all of the major variables on the lift reductions due to jet spoiling are considered. The major problems associated with the analytical treatment of spoiling are presented and the possibility of practical application of the device is considered.</p> <p>The data represents the results of smoke tunnel studies, pressure distribution studies, and flight tests.</p> <p style="text-align: center;">CONFIDENTIAL</p>

Childress, W. S., Gould, A. V. CONFIDENTIAL

Two-dimensional tests of a 23015 airfoil with a jet spoiler and various flaps. Princeton University, Department of Aeronautical Engineering. Report No. 365 - October 1956 - 62 pp. 37 fig.

1. Jet spoilers
2. Lift - reduction
3. Control - Lateral; I. Childress, W. S.; II. Gould, A. V.; III. Princeton University, Department of Aeronautical Engineering. Report No. 365.

CONFIDENTIAL

Childress, W. S., Gould, A. V. CONFIDENTIAL

Two-dimensional tests of a 23015 airfoil with a jet spoiler and various flaps. Princeton University, Department of Aeronautical Engineering. Report No. 365 - October 1956 - 62 pp. 37 fig.

1. Jet spoilers
2. Lift - reduction
3. Control - Lateral; I. Childress, W. S.; II. Gould, A. V.; III. Princeton University, Department of Aeronautical Engineering. Report No. 365.

CONFIDENTIAL

Childress, W. S., Gould, A. V. CONFIDENTIAL

Two-dimensional tests of a 23015 airfoil with a jet spoiler and various flaps. Princeton University, Department of Aeronautical Engineering. Report No. 365 - October 1956 - 62 pp. 37 fig.

1. Jet spoilers
2. Lift - reduction
3. Control - Lateral; I. Childress, W. S.; II. Gould, A. V.; III. Princeton University, Department of Aeronautical Engineering. Report No. 365.

CONFIDENTIAL

Childress, W. S., Gould, A. V. CONFIDENTIAL

Two-dimensional tests of a 23015 airfoil with a jet spoiler and various flaps. Princeton University, Department of Aeronautical Engineering. Report No. 365 - October 1956 - 62 pp. 37 fig.

1. Jet spoilers
2. Lift - reduction
3. Control - Lateral; I. Childress, W. S.; II. Gould, A. V.; III. Princeton University, Department of Aeronautical Engineering. Report No. 365.

CONFIDENTIAL

ABSTRACT

CONFIDENTIAL

In an attempt to evaluate the effectiveness of the jet spoiler as a lateral control device, two-dimensional 23015 profiles with several familiar flaps were tested at RN from 1 to .25 x 10⁶. The effects of all of the major variables on the lift reductions due to jet spoiling are considered. The major problems associated with the analytical treatment of spoiling are presented and the possibility of practical application of the device is considered.

The data represents the results of smoke tunnel studies, pressure distribution studies, and flight tests.

CONFIDENTIAL

ABSTRACT

CONFIDENTIAL

In an attempt to evaluate the effectiveness of the jet spoiler as a lateral control device, two-dimensional 23015 profiles with several familiar flaps were tested at RN from 1 to .25 x 10⁶. The effects of all of the major variables on the lift reductions due to jet spoiling are considered. The major problems associated with the analytical treatment of spoiling are presented and the possibility of practical application of the device is considered.

The data represents the results of smoke tunnel studies, pressure distribution studies, and flight tests.

CONFIDENTIAL

ABSTRACT

CONFIDENTIAL

In an attempt to evaluate the effectiveness of the jet spoiler as a lateral control device, two-dimensional 23015 profiles with several familiar flaps were tested at RN from 1 to .25 x 10⁶. The effects of all of the major variables on the lift reductions due to jet spoiling are considered. The major problems associated with the analytical treatment of spoiling are presented and the possibility of practical application of the device is considered.

The data represents the results of smoke tunnel studies, pressure distribution studies, and flight tests.

CONFIDENTIAL

ABSTRACT

CONFIDENTIAL

In an attempt to evaluate the effectiveness of the jet spoiler as a lateral control device, two-dimensional 23015 profiles with several familiar flaps were tested at RN from 1 to .25 x 10⁶. The effects of all of the major variables on the lift reductions due to jet spoiling are considered. The major problems associated with the analytical treatment of spoiling are presented and the possibility of practical application of the device is considered.

The data represents the results of smoke tunnel studies, pressure distribution studies, and flight tests.

CONFIDENTIAL

UNCLASSIFIED

UNCLASSIFIED